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Science 20

MODULE 8

Circular Motion and Momentum

Distance Learning

Alberta EDUCATION

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Science 20

Module 8

Circular Motion and Momentum

Alberta EDUCATION

Distance Learning

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Other	

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Student Module
Module 8
Circular Motion and Momentum
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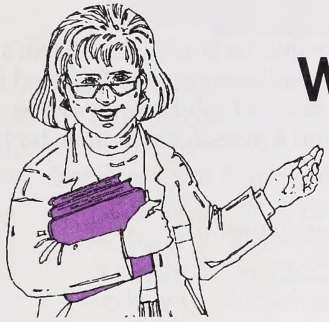
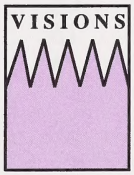


Welcome to Module 8!

We hope you'll enjoy your study of Circular Motion and Momentum.

To make your learning a bit easier, watch the referenced videocassettes whenever you see this icon.

When you see this icon, study the appropriate pages in your textbook.

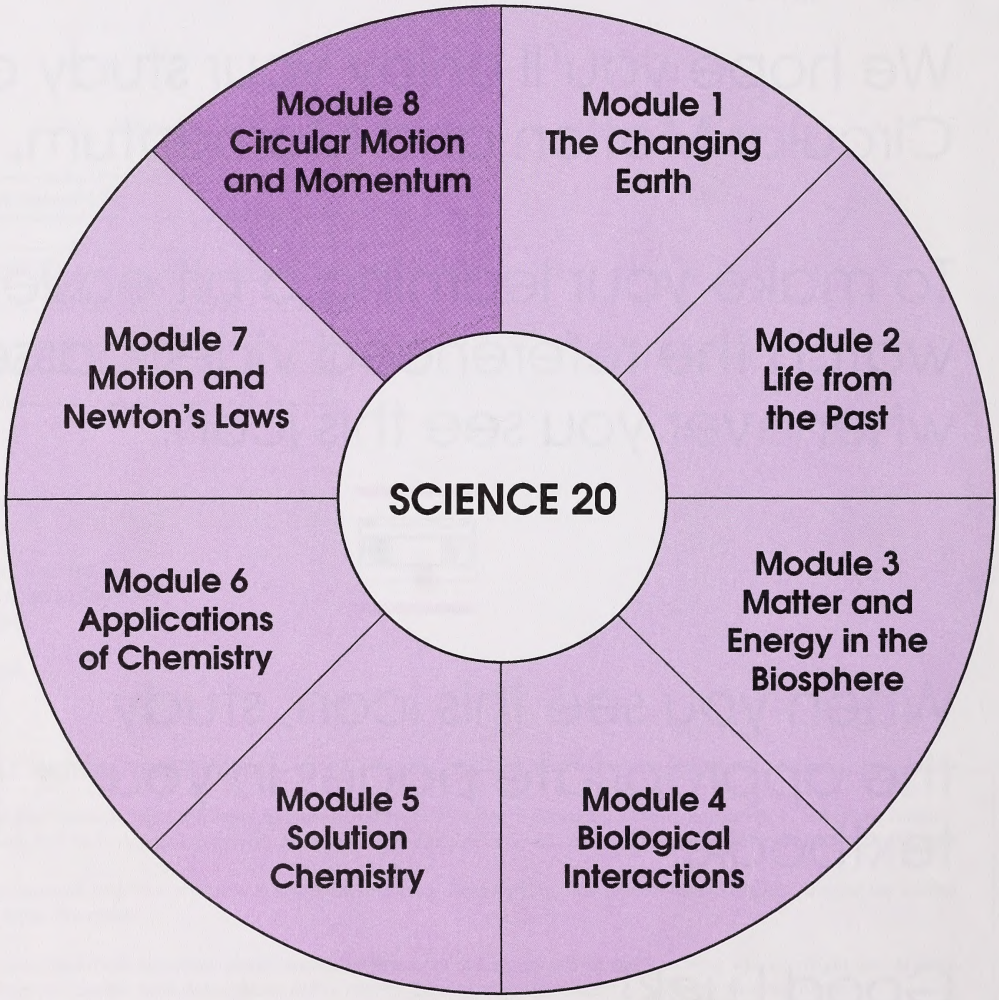


Good Luck!

COURSE OVERVIEW

This course contains eight modules. Modules 1 and 2 involve the study of the Earth's physical features and past life history. Modules 3 and 4 involve the study of life and its interaction with the Earth. Modules 5 and 6 involve the study of solutions as well as how chemistry is used for everyday things. Modules 7 and 8 investigate motion, both on Earth and in space.

The module you are working on is highlighted in a darker colour.



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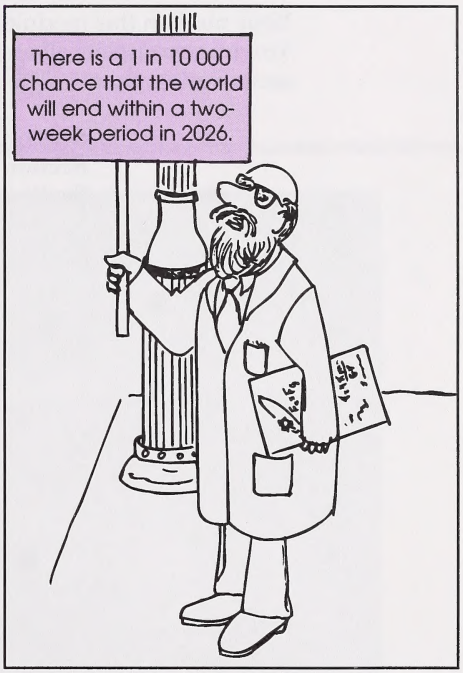
MODULE OVERVIEW

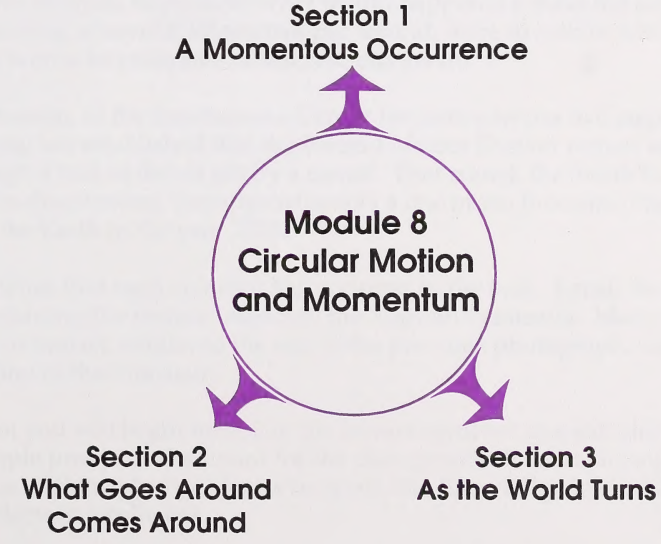
Have you ever stood outside on a warm, clear night in mid-August watching the splendour of the Perseid Meteor Shower? This spectacle occurs annually to the delight of amateur and professional skywatchers alike. Whoever would have thought that the appearance of this meteor shower in the year 2026 may herald the end of civilization, and life, as we know it?



Wait! This isn't one of those doom and gloom proclamations made by some streetcorner person! This comes straight from Dr. Brian Marsden of the Smithsonian Center for Astrophysics in Cambridge, Massachusetts.

How did Dr. Marsden arrive at such an astonishing and dire conclusion? He arrived at such a conclusion by using his knowledge of kinematics, dynamics, and orbital mechanics, as well as his skill at making accurate observations.

The previous module introduced you to the concept of kinematics and dynamics – the how and why of the way objects move. In this module you will expand on those concepts as you study collisions between objects and circular motion.



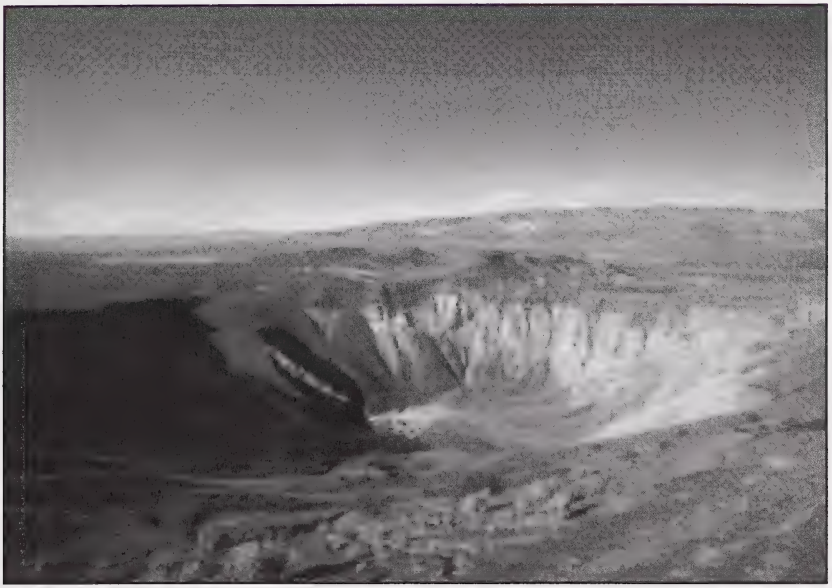
Evaluation

Your mark in this module will be determined by your work in the Assignment Booklet. You must complete all assignments. In this module you are expected to complete three section assignments. The assignment breakdown is as follows:

Section 1 Assignment	**40 marks**
Section 2 Assignment	**35 marks**
Section 3 Assignment	**25 marks**
TOTAL	**100 marks**

Section

1 A Momentous Occurrence



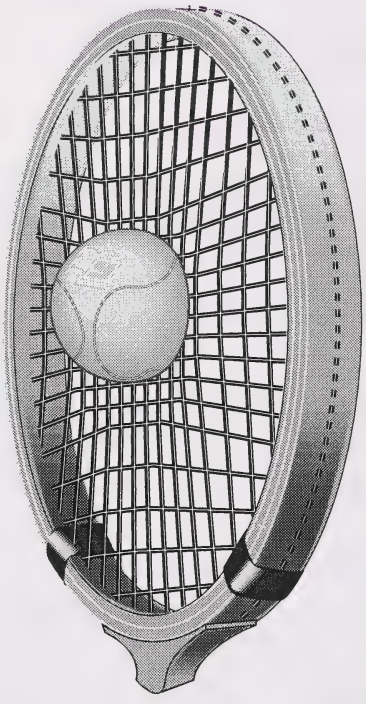
Have you ever stopped to consider what would happen if a mass the size of a small mountain, moving at several kilometres per second, were to collide with the Earth? Would mere words be sufficient to describe this event?

Dr. Brian Marsden, of the Smithsonian Center for Astrophysics in Cambridge, Massachusetts, has established that the Perseid Meteor Shower occurs as the Earth passes through a trail of debris left by a comet. That comet, the Swift-Tuttle Comet (named for its discoverers), has approximately a one in ten thousand chance of intersecting the Earth in the year 2026.

There is evidence that such an event has occurred in the past. Recall the article from Module 2 regarding the meteor impact in the Yucatan Peninsula. Many scientists believe that an impact, similar to the one in the previous photograph, contributed to the mass extinction of the dinosaur.

In this section you will begin to look at the factors involved in a collision and at the way in which people predict and account for the changes which occur during and after a collision. You will then have a chance to apply that knowledge to describe events involving objects in a collision.

Activity 1: Momentum and Impulse Defined



One of the most important facts to keep in mind during your study of collisions is that any collision involves the application of a force. In Module 7 you learned that the force that is applied to an object will result in an acceleration proportional to that force.

However, no collision occurs instantaneously. All collisions occur over some finite amount of time. A good illustration of this is shown in the drawing on the left.

Both objects involved in the collision show evidence of a force being applied over time. In Science 10 you were introduced to the concept of graphical analysis. One of the ways of looking at a collision is to plot the forces which are applied on an object.

For the situation shown – a tennis ball striking a racket – you may observe a plot much like the one in Figure 8.1.

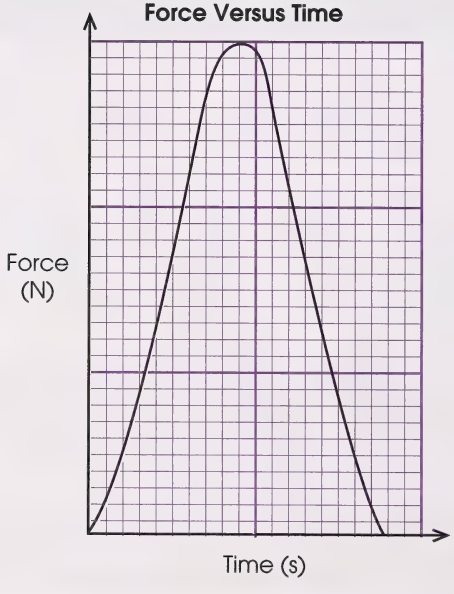


Figure 8.1 Graph of Force Versus Time

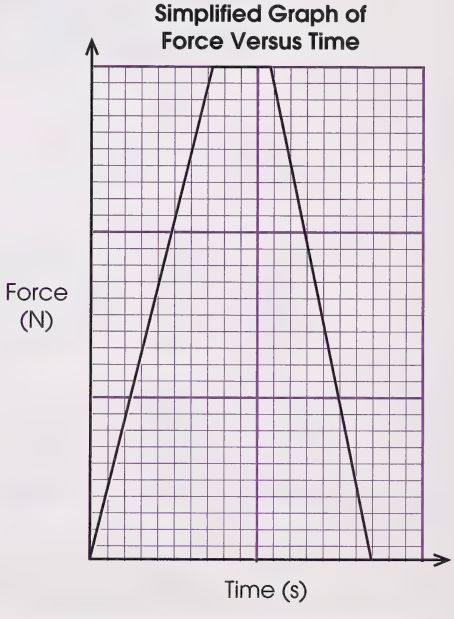


Figure 8.2 Graph of Average Force Versus Time

Since this type of graph is difficult to describe mathematically, it is common to use an averaging technique. Examine the graph in Figure 8.2.

1. Why would the graph shown in Figure 8.2 be easier to describe mathematically?

In Module 7 you learned that the slope of a line, and the area beneath a line, on a graph could represent specific quantities. Do you recall what those quantities were?

2. Complete the following chart.

Type of Graph	Function	Quantity Represented
distance versus time	slope	
	area	
velocity versus time	slope	
	area	

Check your answers by turning to the Appendix, Section 1: Activity 1.

impulse – the product of force applied and time of application

A graph of average force versus time is similar in that the area beneath the line represents a specific quantity. This quantity is called **impulse**.

Impulse is important to the study of any collision since it represents both the strength and duration of the force acting on an object during a collision. This is shown in the following graph.

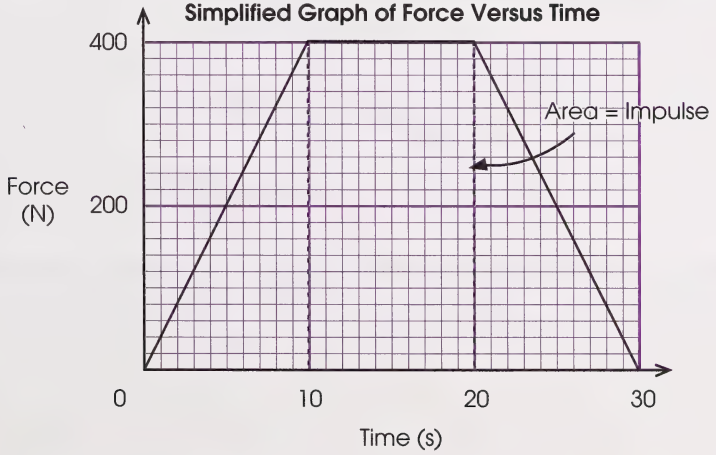


Figure 8.3 Graph of Impulse

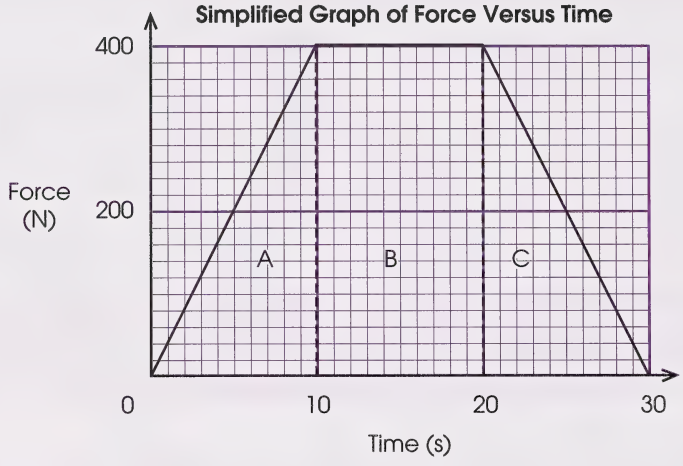
Do you remember how to calculate the area under a line such as the one shown in Figure 8.3? Look at the following example.

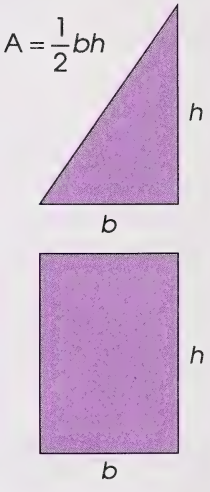
Example: Calculating Impulse

Calculate the impulse of the graph in Figure 8.3.

The solution is as follows:

First, divide the area below the line into rectangles and triangles.





Impulse = Area below the line

$= \text{Area A} + \text{Area B} + \text{Area C}$

$= \frac{1}{2}bh + bh + \frac{1}{2}bh$

$= \frac{1}{2}(10\text{ s})(400\text{ N}) + (10\text{ s})(400\text{ N}) + \frac{1}{2}(10\text{ s})(400\text{ N})$

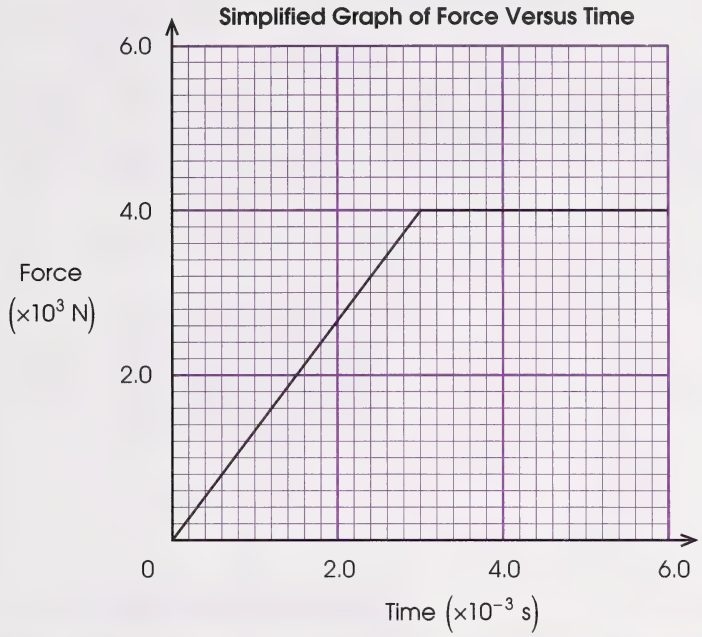
$= 2000\text{ N}\bullet\text{s} + 4000\text{ N}\bullet\text{s} + 2000\text{ N}\bullet\text{s}$

$= 8000\text{ N}\bullet\text{s}$

$= 8.0 \times 10^3\text{ N}\bullet\text{s}$ (2 significant digits)

Be sure to remember to use only simple geometric forms – rectangles and triangles work the best.

3. Given the following graph, calculate the total impulse acting on the object.



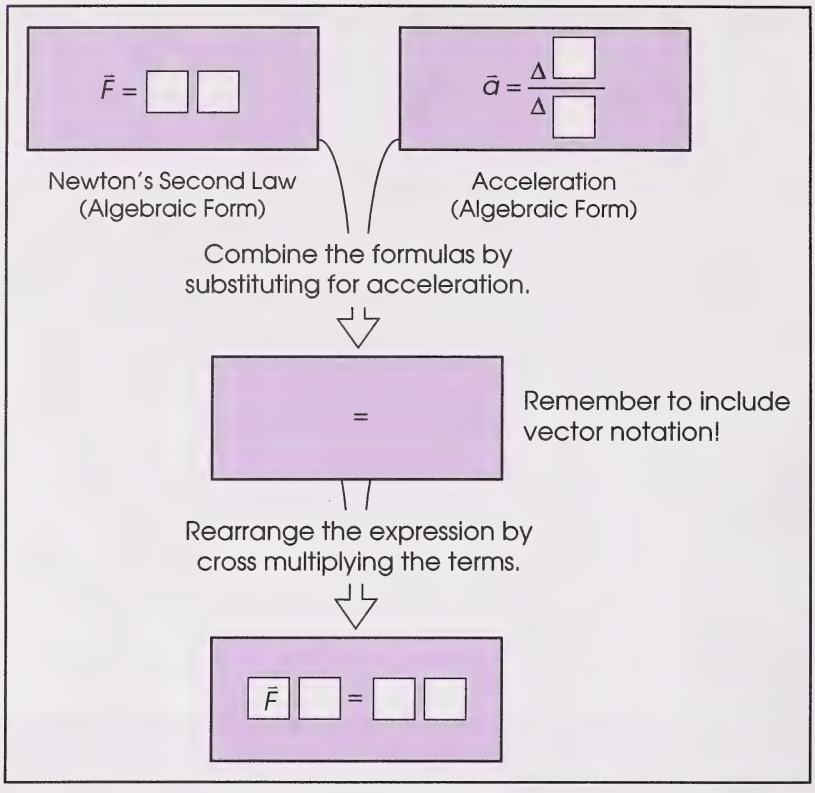
Check your answers by turning to the Appendix, Section 1: Activity 1.

One of the biggest problems with this method is that most collisions occur over relatively short period of time. This makes it extremely difficult to accurately observe and measure the forces acting during a collision. To get around this problem, it is possible to focus on the result of the impulse applied to an object rather than the actual application of the force. But what does an impulse do?

Back in Module 7 you studied Newton's laws of motion. Those laws describe how the force applied relates to motion of an object in a given direction.

4. What does Newton's Second Law tell you about the way in which force relates to motion?

5. Complete the diagram that follows by filling in the appropriate spaces and making the suggested algebraic changes.


$\vec{F} =$ □□
$\vec{a} = \frac{\Delta \square}{\Delta \square}$
Newton's Second Law (Algebraic Form)
Acceleration (Algebraic Form)
Combine the formulas by substituting for acceleration.
=
Remember to include vector notation!
Rearrange the expression by cross multiplying the terms.
$\vec{F}$ □ = □□

6. What does the left side of the final equation found in question 5 represent?

momentum – the product of mass and velocity

The right side of the equation is given a special name in physics. That quantity represents the change in **momentum** for an object. Momentum is represented algebraically by the symbol $\vec{p}$.

7. Give the algebraic formula for the momentum of an object. (Use the definition previously provided.)

Check your answers by turning to the Appendix, Section 1: Activity 1.

Your textbook uses the symbol $\vec{I}$ to represent impulse. You will find that **most** textbooks do not use a symbol for impulse, although in some college-level texts you may find the symbol $\vec{J}$ used.

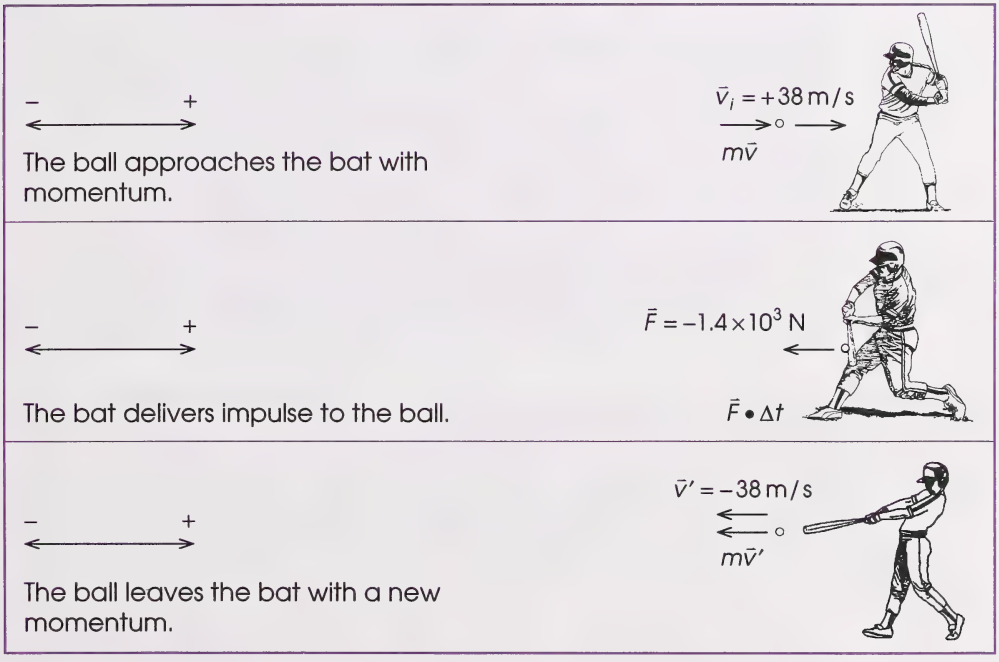
8. Give the algebraic formula for impulse. (You should use either the definition of impulse or your answer to question 6.)

9. If momentum starts with the letter m, and impulse starts with the letter i, why would the symbols $\vec{p}$ and $\vec{J}$ be used to represent momentum and impulse? Can you think of a reason?

Check your answers by turning to the Appendix, Section 1: Activity 1.

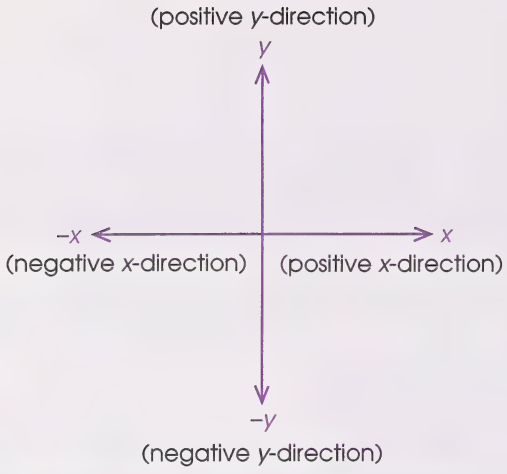
Since *Visions 2* uses the symbol $\vec{I}$ for impulse, you will use $\vec{I}$ for impulse in this module. To distinguish it from I for electric current, remember that impulse is a vector quantity and will always have the vector symbol (-).

The following diagram shows how impulse and momentum are defined in terms of a baseball player hitting a ball.


– +
The ball approaches the bat with momentum.
$\vec{v}_i = +38\ m/s$
$m\vec{v}$
– +
The bat delivers impulse to the ball.
$\vec{F} = -1.4 \times 10^3\ N$
$\vec{F} \bullet \Delta t$
– +
The ball leaves the bat with a new momentum.
$\vec{v}' = -38\ m/s$
$m\vec{v}'$

10. Which direction is negative and which direction is positive for the data in the previous diagrams?

Check your answers by turning to the Appendix, Section 1: Activity 1.



Illustrate the use of the previous formulas in problems. Since impulse, force, velocity, and so on are all vectors, you need to be concerned with direction.

In Module 7 you used direction in mathematical terms where you have a positive x-direction, a negative x-direction, a positive y-direction, and a negative y-direction (as shown in the diagram on the left).

The problems in Module 8 will continue to show direction using this mathematical method.

Example: Momentum

What is the momentum of a 45.0 kg child running in a positive x-direction at 3.00 m/s?

The solution is as follows:

$$\vec{p} = m\vec{v}$$
$$= (45.0\ \text{kg})(3.00\ \text{m/s})$$
$$= 135\ \text{kg} \bullet \text{m/s, in a positive } x\text{-direction}$$

Example: Impulse

An average force of 7.50×10^5 N directed in a negative x-direction stops a car which is travelling in a positive x-direction in a time of 0.120 s. What is the impulse acting on that car?

The solution is as follows:

$$\vec{I} = \vec{F}\Delta t$$
$$= \left(-7.50 \times 10^5\ \text{N}\right)(0.120\ \text{s})$$
$$= -9.00 \times 10^4\ \text{N} \bullet \text{s}$$
$$= 9.00 \times 10^4\ \text{N} \bullet \text{s, in a negative } x\text{-direction (3 significant digits)}$$

Remember to follow the conventions mentioned earlier in Module 7.

11. a. What is the momentum of a 1000 kg car travelling at 30.0 m/s in a positive y-direction?

    b. What is the velocity needed for a 3000 kg truck to have the same momentum as the car in 11.a.?

12. An impulse of 4.76×10^{-2} N • s acts on a small mass in a positive x-direction. If the duration of the impulse was 0.170 s, what was the average force acting on that mass?

Check your answers by turning to the Appendix, Section 1: Activity 1.

In question 5 of this activity, you may have noticed that an impulse is needed to cause a change in momentum in a particular direction.

$$\boxed{\vec{F}\Delta t = m\Delta\vec{v}} \quad \text{(where Impulse} = \vec{F}\Delta t\text{)}$$

or

$$\boxed{\vec{F}\Delta t = \Delta\vec{p}} \quad \text{(where } \Delta\vec{p} = \text{change in momentum)}$$

This formula proves to be very useful in describing the interaction between the application and results of a force.

Example:

A 55.0 kg person falls from a ladder and lands on the floor. The person's speed just before impact is 7.00 m/s, and then comes to a stop in 5.80×10^{-2} s. Assume the direction as a negative y-direction.

a. What was the person's momentum before impact?

b. What was the person's final momentum?

c. What was the change in momentum?

d. What was the average force acting on the person during the impact?

The solutions are as follows:

a. $\vec{p} = m\vec{v}$

$= (55.0\text{ kg})(-7.00\text{ m/s})$

$= -385\text{ kg} \bullet \text{m/s}$

$= 385\text{ kg} \bullet \text{m/s}$, down or in negative y-direction

b. The person's final momentum was zero.

c. $\Delta\vec{p} = \vec{p}_f - \vec{p}_i$

$= 0 - (-385\text{ kg} \bullet \text{m/s})$

$= +385\text{ kg} \bullet \text{m/s}$

$= 385\text{ kg} \bullet \text{m/s}$, up or in positive y-direction

d. $\vec{F}\Delta t = \Delta\vec{p}$

$$\vec{F} = \frac{\Delta\vec{p}}{\Delta t}$$

$$= \frac{+385\text{ kg} \bullet \text{m/s}^2}{5.80 \times 10^{-2}\text{ s}}$$

$= +6.64 \times 10^3\text{ kg} \bullet \text{m/s}^2$ (3 significant digits)

The average force was approximately 6.64×10^3 N up, or in a positive y-direction.

Now it is your turn to put the steps together. Do the following question.

13. A 56.7 g tennis ball travelling 25.0 m/s, in a negative x-direction, hits a brick wall and, after an impact time of 2.50×10^{-3} s, rebounds in the opposite direction at 24.0 m/s. What was the average force acting on the tennis ball during the collision?

Check your answers by turning to the Appendix, Section 1: Activity 1.

You have used formulas which allow you to calculate the results of an impulse provided to a mass or by knowing the results to calculate the impulse. You have learned that impulse and momentum are related. In the next activity you will perform an investigation which illustrates the conservation of momentum.

Activity 2: Development of the Law of Conservation of Momentum

In Activity 1 you were introduced to the concepts of momentum and impulse. Impulse was defined as the product of a force and the time over which that force was applied. Newton's Second Law was rewritten to show that the impulse applied to a mass is equal to the change in momentum of that mass. However, one thing that was not really considered was that more than one object, force, or change in momentum may be involved in the application of a force.

For example, in Activity 1 you were asked to study a drawing of a tennis ball striking a racket.

1. What evidence is there that more than one force is acting at the same time?

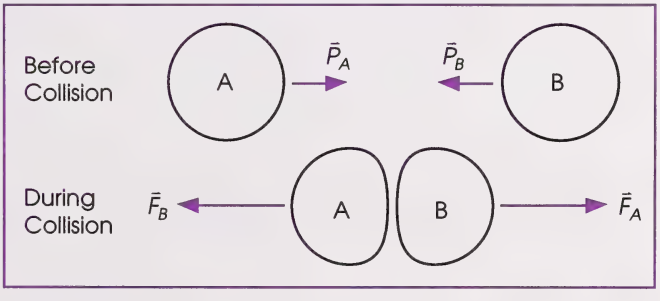
You may wish to note that this is exactly as would be expected from Newton's Third Law! Do you remember that law?

2. State Newton's Third Law.

Check your answers by turning to the Appendix, Section 1: Activity 2.

Newton's Third Law forms the basis for describing the events and results of objects interacting with each other.

For any interaction, the changes in motion which occur must be a result of the forces which are acting.



Notice that the force of object B is acting on object A, and the force of object A is acting on object B.

The following shows how the formula for the Law of Conservation of Momentum is obtained from Newton's second and third laws using a collision of two balls labelled A and B.

From Newton's Third Law

$$\vec{F}_A = -\vec{F}_B$$

From Newton's Second Law

$$\vec{F}\Delta t = m\Delta\vec{v}$$

or

$$\vec{F}\Delta t = \Delta\vec{p}$$

$$\vec{F} = \frac{\Delta\vec{p}}{\Delta t}$$

$$\frac{\Delta\vec{p}_A}{\Delta t} = \frac{-\Delta\vec{p}_B}{\Delta t}$$ (Substitute $\frac{\Delta\vec{p}}{\Delta t}$ for $\vec{F}$ in $\vec{F}_A = -\vec{F}_B$.)

$$\Delta\vec{p}_A = -\Delta\vec{p}_B$$ (For the collision, Δt is the same.)

This formula is based on the total momentum before and after the collision and can also be written in the following form.

$$\Delta\vec{p}_A + \Delta\vec{p}_B = 0$$

For a more detailed discussion of how the Law of Conservation of Momentum is obtained from Newton's second and third laws, read pages 504 and 505 of *Visions* 2.

3. In sentence form, state the Law of Conservation of Momentum.

4. What assumption is made about the forces acting on ball A and ball B when it is stated that $F_{AB} = -F_{BA}$. What part of the Law of Conservation of Momentum is this assumption restating.

5. What does the equation $\Delta\vec{p}_A = -\Delta\vec{p}_B$ tell you about the transfer of momentum from one object to another?

Check your answers by turning to the Appendix, Section 1: Activity 2.

In the previous equation, the total momentum before or after a collision is considered as one. You can also look at conservation of momentum of a collision in terms of the sum of the momenta of each of the objects involved.

When looked at in this way, the sum of the momenta of each of the objects before the collision is equal to the sum of the momenta of each of the objects after the collision. Algebraically, this can be written as follows:

$$\vec{p}_A + \vec{p}_B = \vec{p}_A{}' + \vec{p}_B{}'$$

The momentum after the collision is denoted with $(')$; this is called the prime symbol.

Since $\vec{p} = m\vec{v}$, you can rewrite the previous equation as follows:

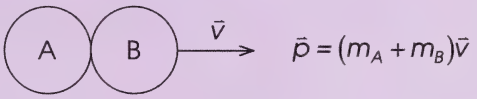
$$m_A\vec{v}_A + m_B\vec{v}_B = m_A\vec{v}_A{}' + m_B\vec{v}_B{}'$$

You will often see this equation with the numbers *1* and *2* in place of the letters *A* and *B* to indicate the objects. If you know the masses, this equation can be used to calculate the velocities before a collision and the velocities after a collision. You will use this law only for linear collisions.

This law was actually first written shortly before the time of Isaac Newton; but it is only since Newton that it has been expressed as a mathematical relation.

Using this general law is easy, especially if you keep the following restrictions in mind.

1. Any moving object has a momentum which must be accounted for.
2. Any objects connected together have a common momentum.



3. Momentum is a vector quantity – directions make a difference. You will be concerned with collisions which continue in the same direction or collisions which rebound in the opposite direction.

isolated system – a group of objects that experience a net force of zero due to forces outside the group

Before you get the idea that the only thing that the Law of Conservation of Momentum describes is the result of a collision, you should note the following rule. The Law of Conservation of Momentum describes any **isolated system**.

VISIONS

One of the best examples of this idea is the use of rocket engines to move spacecraft through a vacuum. For more information relating to this, carefully read the section entitled Conservation of Momentum Explains Some Forms of Propulsion and Recoil on page 513 of your textbook.

6. Explain how a rocket is able to move itself forward in empty space if, by definition, there is nothing for it to push against.

Check your answers by turning to the Appendix, Section 1: Activity 2.

In Activity 3 you will have the opportunity to practise the use of the Law of Conservation of Momentum to solve simple problems relating to collisions and explosions (recoils). But first you need to check the validity of this law.

Investigation: Conservation of Momentum

Follow the directions of this investigation carefully. Pay special attention to the required components, safety aspects, and applied science skills.

Background Information

Although momentum is the product of mass and velocity, it is possible, in this experiment, to avoid measuring the velocity and express momentum in terms of more easily measured quantities.

Since $\vec{v} = \frac{\Delta \vec{d}}{\Delta t}$ and $\vec{p} = m\vec{v}$, then $\vec{p} = \frac{m\Delta \vec{d}}{\Delta t}$. $\Delta \vec{d}$ represents the displacement (distance and direction) of the cart, and Δt represents the time for which the cart moves.

For Cart A and Cart B, if momentum is conserved before and after the collision, then $\vec{p}_A = -\vec{p}_B$. Since $\vec{p} = m\frac{\Delta \vec{d}}{\Delta t}$, then $m_A \frac{\Delta \vec{d}_A}{\Delta t_A} = -m_B \frac{\Delta \vec{d}_B}{\Delta t_B}$.

Since each dot is placed at the same time on each tape in a run, Δt is the same for the same number of dots and will cancel from each side to get $m_A \Delta \vec{d}_A = -m_B \Delta \vec{d}_B$. Thus, you need only measure mass and displacement of each cart for this experiment. If you show that $m_A \Delta \vec{d}_A = -m_B \Delta \vec{d}_B$, then you can say that $\vec{p}_A = -\vec{p}_B$ since $\vec{p} \propto m\vec{d}$ (momentum is proportional to mass times displacement).

PATHWAYS

If you have access to laboratory facilities, do Part A. If you do not have access to laboratory facilities, do Part B.

Part A involves the collection of data for use in verifying the Law of Conservation of Momentum. Part B provides those students without access to laboratory facilities with sample data for the experiment described. The data may be used to complete this investigation.

Science Skills

- ☐ A. Initiating
- ☑ B. Collecting
- ☑ C. Organizing
- ☑ D. Analysing
- ☐ E. Synthesizing
- ☐ F. Evaluating

Part A

Purpose

Perform an experiment, collect data, and analyse data to illustrate the Law of Conservation of Momentum.

Materials

- ruler or metre stick
- 2 dynamics carts (one with spring-loaded plunger)
- ticker tape timer with ticker tape
- 2 pencils
- strong elastic bands
- masking tape
- laboratory mass set
- triple beam balance or electronic balance

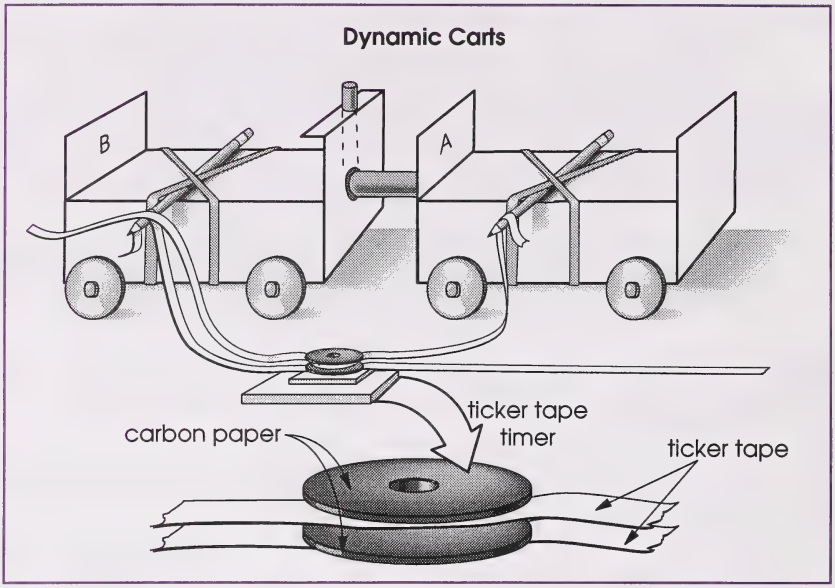
Procedure

Step 1: Set up the apparatus as in the diagram immediately following Step 4. Make sure the carts have a clear pathway in which to move.

Step 2: Attach a pencil to extend out from each cart using crossed elastic bands to hold the pencil in place. Connect a ticker tape to each pencil.

Step 3: Start the ticker tape timer and initiate the "explosion" by pushing down on the trigger. (An alternative is to tie the carts together with a string, and cut the string with scissors.) The carts should move away from each other pulling the ticker tape behind them.

Step 4: Label the ticker tapes obtained for later reference. Measure the mass of each cart and record the mass on the appropriate ticker tape.



Step 5: Repeat Steps 2 to 4 two more times using different masses each time. You may adjust the mass of a cart by adding a mass from your mass set. Add about 200 g to each cart for each additional trial.

Step 6: For each tape draw a line through the first dot and count off 34 more dots. Draw a line through the last dot counted.

Step 7: Measure the distance (to the nearest tenth of a centimetre) between the lines marked on the tape. Record this distance in the appropriate place on the data chart in the Observations section. Assume Cart A to be going in the positive direction and Cart B to be in the negative direction.

Step 8: Record the mass that corresponds to each of the tapes in the appropriate place on the data chart in the Observations section.

Step 9: For each trial, calculate the product of mass and displacement $\left(m\Delta\vec{d}\right)$ for each of Carts A and B. Record those values in the appropriate space on the data table in the Observations section.

Step 10: Calculate the average of the product of mass times displacement $\left(m\Delta\vec{d}\right)$ for the three trials for each cart.

Observations

7. Copy and complete the following data charts for Cart A and Cart B. The displacement will be positive for Cart A and negative for Cart B.

Cart A			
Trial Run	Mass of Cart A m_A (g)	Displacement of Cart A $\Delta\vec{d}_A$ (cm)	Product of Mass and Displacement for Cart A $m_A\Delta\vec{d}_A$ (g • cm)
1			
2			
3			

Cart B			
Trial Run	Mass of Cart B m_A (g)	Displacement of Cart B $\Delta\vec{d}_A$ (cm)	Product of Mass and Displacement for Cart B $m_A\Delta\vec{d}_A$ (g • cm)
1			
2			
3			

8. Calculate the average of $m_A\Delta\vec{d}_A$ and $m_B\Delta\vec{d}_B$.

Check your answers by turning to the Appendix, Section 1: Activity 2.

End of Part A

You may now proceed to the Analysis and Interpretation portion of this investigation which follows Part B.

Science Skills

- ☐ A. Initiating
- ☐ B. Collecting
- ☑ C. Organizing
- ☑ D. Analysing
- ☐ E. Synthesizing
- ☐ F. Evaluating

Part B

Purpose

Analyse data to illustrate the Law of Conservation of Momentum.

Materials

- ticker tape results (given at the end of the Appendix)
- scissors
- centimetre ruler (given at the end of the Appendix)
- transparent, adhesive tape

Procedure

Step 1: Locate the three sets of ticker tapes at the end of the Appendix.

Step 2: Copy and carefully cut out each ticker tape. Tape the ticker tapes together as soon as you cut out one trial set. Match the labelled ends (1 to 1, 2 to 2) when you tape them together. Tape the three ticker tapes for each trial as straight as possible. You might use the edge of a desk or table to help line up the strips.

Step 3: Follow Steps 6 to 10 in Part A for information on how to measure and record the displacement between the points.

Observations

9. Copy and complete a data chart like the one in the Observations section of Part A.

Check your answers by turning to the Appendix, Section 1: Activity 2.

End of Part B

Analysis and Interpretation

For this experiment $\vec{p}_A$ should equal $\vec{p}_B$.

$$\vec{p}_A + \vec{p}_B = 0$$
$$\vec{p}_A = -\vec{p}_B$$

You learned previously that $\vec{p} = m\vec{v}$. However, since you found displacement and not velocity, you can say the following:

$$m_A \Delta \vec{d}_A = -m_B \Delta \vec{d}_B$$
$$2.54 \times 10^4 = -\left(-2.58 \times 10^4\right)$$
$$2.54 \times 10^4 = 2.58 \times 10^4$$

10. What can you say about the product of mass and displacement for Cart A compared to Cart B?

11. Since $\vec{p} \propto m\Delta\vec{d}$, what can you say about the momentum for Cart A compared to Cart B? Do you agree that momentum is conserved?

12. Why are the values for $\Delta\vec{d}$ and $m_B \Delta \vec{d}_B$ listed as negative?

13. Most surfaces are not completely level. This would mean that $\vec{p}_A$ and $\vec{p}_B$ will not equal each other since one of the carts will accelerate slightly and the other will decelerate slightly. How could you overcome this problem?

Check your answers by turning to the Appendix, Section 1: Activity 2.

Activity 2 allowed you to develop and confirm the Law of Conservation of Momentum. You will make use of this law to solve simple calculation problems in Activity 3.

Activity 3: Application of the Law of Conservation of Momentum

The Law of Conservation of Momentum describes the results of a collision or explosion (recoil) based on the original conditions. Study the following examples to see a way in which you may use the Law of Conservation of Momentum to solve for a required quantity.

Example:

A 400 g dynamics cart travelling in a positive *x*-direction at 10.0 cm/s collides directly with a stationary dynamics cart which has a mass of 350 g. After the collision, the 400 g cart continues to move in a positive *x*-direction at 2.00 cm/s. What is the final velocity of the second cart?

The solution is as follows:

Assign a momentum to every moving object. A prime sign is used to distinguish initial and final values. Many textbooks use *i* and *f* subscripts instead, but the prime sign is much simpler.

The total momentum before the collision equals the total momentum after the collision. (In this problem you have one object with momentum before the collision and two objects with momentum after the collision.)

$$\vec{p}_A = \vec{p}_A{}' + \vec{p}_B{}'$$

$$m_A\vec{v}_A = m_A\vec{v}_A{}' + m_B\vec{v}_B{}' \quad (\text{since } \vec{p} = m\vec{v})$$

Substitute the values for mass and velocity given in the question. Remember to distinguish between directions. Use a positive sign for velocity if the direction is toward the positive *x*- or *y*-direction. Use a negative sign for velocity if the direction is toward the negative *x*- or *y*-direction.

$$(400\text{ g})(+10.0\text{ cm/s}) = (400\text{ g})(+2.00\text{ cm/s}) + (350\text{ g})\left(\vec{v}_B{}'\right)$$

$$4.00\times10^3\text{ g}\bullet\text{cm/s} = 800\text{ g}\bullet\text{cm/s} + (350\text{ g})\left(\vec{v}_B{}'\right)$$

$$\vec{v}_B{}' = \frac{4.00\times10^3\text{ g}\bullet\text{cm/s} - 800\text{ g}\bullet\text{cm/s}}{350\text{ g}} \quad \left(\text{Solve for } \vec{v}_B{}'.\right)$$

$$= +9.14\text{ cm/s}$$

$$= 9.14\text{ cm/s, in a positive } x\text{-direction}$$

(2 significant digits)

The final velocity of the second cart is approximately 9.14 cm/s in a positive *x*-direction.

Remember that the sign of your answer, positive or negative, will be determined by the direction in which the object in question moves. You must be careful to follow the restrictions mentioned in Activity 2. Here is another example for you to study.

Example:

A 2.00×10^3 kg truck travelling in a negative x-direction at 30.0 km/h collides with a 1.20×10^3 kg car moving in a positive x-direction at 40.0 km/h. If the vehicles remained locked together after impact, what is the final velocity of the wreckage?

The solution is as follows:

Total momentum before the collision equals total momentum after the collision. (There are two objects before the collision and one connected object after the collision.)

$$\vec{p}_A + \vec{p}_B = \vec{p}_{AB}$$

$$m_A\vec{v}_A + m_B\vec{v}_B = (m_A + m_B)\vec{v}_{AB}'$$

$$(2.00 \times 10^3 \text{ kg})(-30.0 \text{ km/h}) + (1.20 \times 10^3 \text{ kg})(40.0 \text{ km/h}) = (2.00 \times 10^3 \text{ kg} + 1.20 \times 10^3 \text{ kg})(\vec{v}_{AB}')$$

$$-6.00 \times 10^4 \text{ kg} \bullet \text{km/h} + 4.80 \times 10^4 \text{ kg} \bullet \text{km/h} = (3.20 \times 10^3 \text{ kg})(\vec{v}_{AB}')$$

$$\vec{v}_{AB}' = \frac{-6.00 \times 10^4 \text{ kg} \bullet \text{km/h} + 4.80 \times 10^4 \text{ kg} \bullet \text{km/h}}{(3.20 \times 10^3 \text{ kg})}$$

$$= -3.75 \text{ km/h}$$

$$= 3.75 \text{ km/h, in a negative } x\text{-direction}$$

The final velocity of the wreckage is 3.75 km/h in a negative x-direction.

Note: The masses are added together after the collision because the objects are connected.

The following questions will allow you to practise the use of the Law of Conservation of Momentum. It is not necessary to do all of the questions, but you should do at least two questions from Part A, two questions from Part B, and one of the questions from Part C. Remember to include directions as required.

Part A

1. A 3.00×10^4 kg box car is travelling in a positive x-direction at 4.00 m/s when it collides with and remains coupled (stuck) to a stationary 5.00×10^4 kg freight car. Calculate the velocity of the cars after the collision.

2. A 15.0 kg object travelling in a positive x-direction at 5.50 m/s collides with and remains stuck to a 6.00 kg object moving in a negative x-direction at 8.00 m/s. What is the velocity of the combined mass after the collision?

3. A 150 g steel ball rolling in a positive y-direction at 300 cm/s collides directly with a 400 g steel ball initially at rest. Immediately after the collision the 400 g steel ball moves at 85.0 cm/s in a positive y-direction. What is the velocity of the 150 g steel ball?

Part B

4. A 20.0 g bullet moving in a positive x-direction at 600 m/s strikes and then remains lodged in a stationary block of wood. After the collision, the block of wood (and bullet) moves in a positive x-direction at 35.0 m/s. What is the mass of the wood block?

5. A 200 g steel ball moving in a negative x-direction at 100 cm/s strikes a 500 g steel ball moving in a negative x-direction at 60.0 cm/s. After the collision, the 500 g steel ball moves in a negative x-direction at 75.0 cm/s. What is the final velocity of the 200 g steel ball?

6. A 60.0 kg skateboarder is moving in a positive x-direction at 2.00 m/s while standing on a 3.00 kg skateboard. The skateboarder jumps off with a velocity of 0.100 m/s in a negative x-direction. What is the final velocity of the skateboard?

Part C

7. A 100 kg astronaut is standing on the outside surface of a 4.50×10^4 kg spacecraft. The astronaut jumps away from the spacecraft at 8.00 m/s.

   a. What happens to the spacecraft?

   b. What is the velocity of the spacecraft relative to the astronaut? Assume the direction of the astronaut is positive.

8. In the earliest manned orbital missions, all astronauts who were intended to perform a "spacewalk" were issued with a 0.45 calibre pistol to be worn on the outside of their space suit.

   a. What was the purpose in carrying a pistol?

   b. A 100 kg astronaut, including space suit has become separated from the ship which floats 2.00 km away. The pistol can fire one 50.0 g bullet at 300 m/s. The astronaut has 4.00 h of oxygen remaining. Can the astronaut make it back to the spacecraft before the oxygen runs out?

Check your answers by turning to the Appendix, Section 1: Activity 3.

The problems found in this activity represent simple applications of the conservation of momentum for linear motion. In Section 2 of this module you will analyse a different type of motion called circular motion.

Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

All collisions involved the application of a force. That applied force may cause a change in the motion of the object on which it acts.

1. What two simple aspects of the motion of an object can you change with the application of a force?

2. What does Newton's First Law tell you about the motion of any object?

3. Is it easier to change the motion of an object having a large mass or having a small mass? Why?

4. All collisions take some amount of time to occur. Rewrite Newton's Second Law $\left(\vec{F} = m\vec{a}\right)$ so that time appears as a variable in the formula.

5. Copy and complete the following chart.

Quantity	Definition	Formula
Force		
		$\vec{v} = \frac{\Delta \vec{d}}{\Delta t}$
		$\vec{I} = \vec{F}\Delta t$
	the product of the mass and velocity for a moving object	

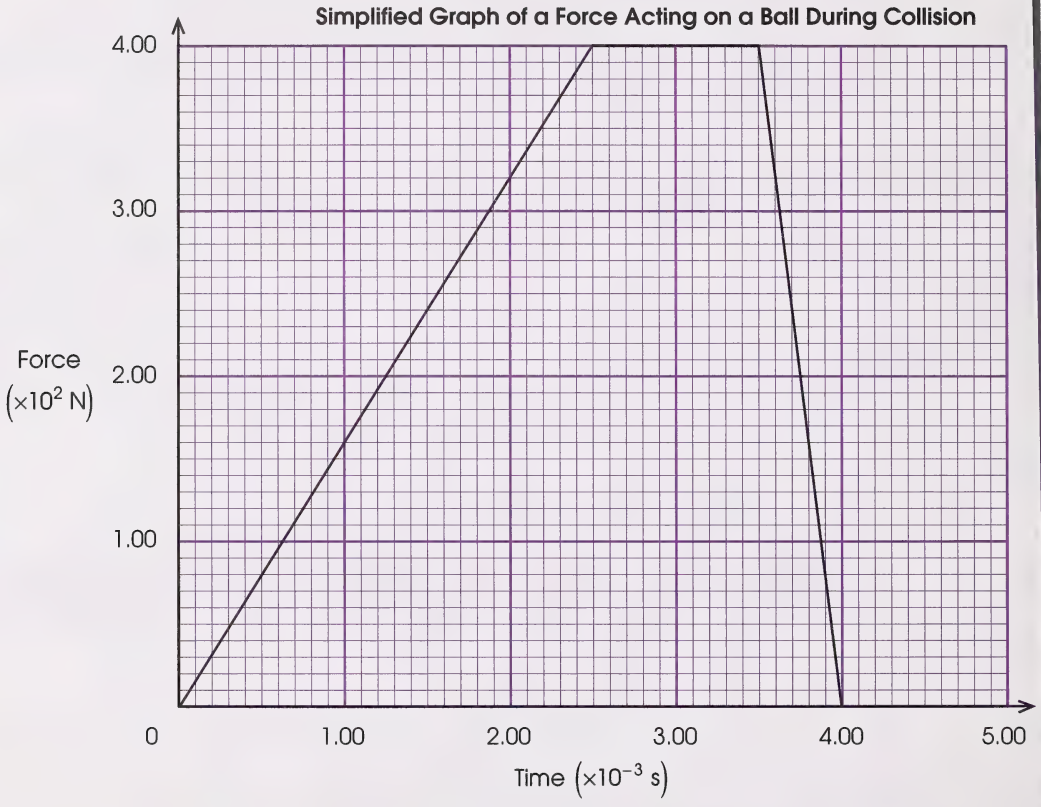
6. A 2000 kg car is moving in a positive x-direction at 27.8 m/s when it slams into a brick wall and crushes to a stop in six one-hundredths of a second $\left(6.00\times10^{-2}\ \text{s}\right)$.

   a. What was the initial momentum of the car before the collision with the wall?

   b. What is the change in momentum of the car because of the collision?

   c. Using the impulse-momentum formula, find the force which acted on the car.

7. Do a. and b. given the following graph.



   a. Find the total impulse which acts on the ball.
   b. Find the change in velocity of the ball if it has a mass of 50 g.

8. A 6.00 kg object moving in a positive x-direction at 3.00 m/s collides with a 10.0 kg object moving in a positive x-direction at 2.00 m/s. After the collision occurs, the 10.0 kg object moves east with a velocity of 2.50 m/s. What would be the velocity of the 6.00 kg object after the collision?

9. Two ice skaters stand facing each other at centre ice of a hockey rink. The skaters push against each other such that the first skater (m = 60.0 kg) travels towards one goal at 3.00 m/s. The second skater moves towards the opposite goal at 4.00 m/s. What is the mass of the second skater? Assume the direction of the first skater to be positive.

10. Using the concept of impulse, explain why newer cars have collapsible bumpers (bumpers made to collapse on impact.)

Check your answers by turning to the Appendix, Section 1: Extra Help.

Enrichment

VISIONS

Carefully read the case study Analysing Traffic Accidents found on page 510 of *Visions* 2.

1. According to the case study what is the first step taken by a traffic investigator at the scene of a crash?

2. Estimates made by the investigator are an integral part of the analysis of a crash. What estimates are made, and what specific information is needed to make those estimates?

3. According to the estimates made, the magnitude of the momentum of Car 1, after the crash, could be found by the following:

$$\begin{aligned}\vec{p} &= m\vec{v} \\ &= (1500\ \text{kg})(58\ \text{km/h}) \\ &= 8.7\times10^{4}\ \text{kg}\bullet\text{km/h}\end{aligned}$$

Calculate the magnitude of the momentum of Car 2 after the crash.

Check your answers by turning to the Appendix, Section 1: Enrichment.

In Module 7 you looked at resolving a vector into a horizontal part and a vertical part using scale diagrams.

4. Using scale diagrams given for Car 1 and Car 2 on page 510 of *Visions 2*, find the perpendicular components (horizontal and vertical components) for the momentum of Car 1 and Car 2 after the collision. (Hint: For Car 1, use a scale of $1\,\text{cm} = 8.7 \times 10^3\ \text{kg} \bullet \text{km/h}$.)

Check your answers by turning to the Appendix, Section 1: Enrichment.

The Law of Conservation of Momentum states that for any collision, the total momentum before the crash must equal the total momentum after the crash. For collisions in more than one dimension you will need to focus on the horizontal and vertical directions. For example, Car 1 only has momentum in the horizontal direction before the collision, whereas Car 2 only has momentum in the vertical direction.

5. Applying the Law of Conservation of Momentum independently to the horizontal and vertical directions produces the following set up. Complete the table by completing the calculation for the vertical momentum in question 4.

Horizontal	Vertical
Total momentum before the collision is equal to total momentum after the collision.	Total momentum is equal to the total momentum after the collision.
$\vec{p}_1 + \vec{p}_2 = \vec{p}_{1\text{hor}}' + \vec{p}_{2\text{hor}}'$ $\vec{p}_1 + 0 = \left(7.7 \times 10^4 + 7.6 \times 10^4\right) \text{kg} \bullet \text{km/h}$ $= 1.5 \times 10^5\ \text{kg} \bullet \text{km/h}$ (2 significant digits)	

6. Knowing the initial momentum, it is then possible to calculate the initial velocity of each car. Calculate the initial velocity of each car before the collision. (Use the results from question 5.)

7. Based on your calculations in question 5, which car was speeding? Does this agree with the conclusions of the traffic investigator?

Check your answers by turning to the Appendix, Section 1: Enrichment.

Conclusion

You may be relieved to know that Dr. Marsden has cancelled his collision alert! It seems that recently translated records of observations made over 2000 years ago by Chinese astronomers have allowed Dr. Marsden to discard inaccurate observations made in the 1800s. Dr. Marsden's original prediction was based in part on the 1800s records which he considered to be of dubious accuracy. With the more accurate results by those ancient astronomers, Dr. Marsden was able to establish the orbit of the Swift-Tuttle comet, and thus cancel the alert.

In Sections 2 and 3 you will be introduced to the ideas of satellite motion and the scientists and models which have been involved in the description of how objects move through space.

ASSIGNMENT

Turn to your Assignment Booklet and do the assignment for Section 1.

Section

2 What Goes Around Comes Around

WESTFILE INC.

Have you ever been on a carnival ride like the one in the photograph? Why do you swing further out as the operator increases the velocity of the ride? How often did you spend a beautiful summer day sitting on a merry-go-round watching the world go by when you were a child? Okay, so it was actually you going round and not the world – but it was still fun! Do you remember holding on for dear life as your friends made the merry-go-round spin faster and faster? Do you remember how much harder it was to stay on as you moved to the outside edge?

Those childhood memories will be of great value during this section as you explore and confirm the factors which contribute to circular motion. From your knowledge and experience of circular motion and the way in which forces determine motion, you will derive a general algebraic formula to describe circular motion. A laboratory investigation will help you to confirm and refine that algebraic description. Finally, you will demonstrate your understanding of circular motion by solving problems relating to circular motion.

Activity 1: Circular Motion

Everyone has had at least a passing acquaintance with aspects of circular motion. You may have experienced circular motion on a merry-go-round, on a swingset, in a car on a winding road, and so on.

What is so special about circular motion? For a start, it is not natural for objects to travel in circles. You learned that in Module 7. Do you recall Newton's Laws of Motion?

1. State Newton's First Law.

Check your answers by turning to the Appendix, Section 2: Activity 1.

According to Newton's First Law, a force is needed to cause any object to deviate from a straight line path. Which do you think would be harder to move in a circular path, a large mass or a small mass? An easy way to settle the matter is to test this.

Science Skills

- ☐ A. Initiating
- ☑ B. Collecting
- ☑ C. Organizing
- ☑ D. Analysing
- ☐ E. Synthesizing
- ☐ F. Evaluating

Investigation: The Factors of Circular Motion

Follow the directions of this investigation carefully. Pay special attention to the required components, safety aspects, and applied science skills.

Purpose

Compare the amount of force needed to spin a large and small mass in a circle.

Materials

- stout cord (approximately 1.00 m in length)
- plastic container with a handle (e.g., plastic milk jug)

Procedure

Caution

Step 1: Secure the cord to the handle of the plastic container. Be sure to tie the knot securely.

Step 2: Holding one end of the cord, swing the empty container through five complete circles. Make sure no one is standing too close.

Step 3: Stop the container, and fill it one-quarter full with water. Swing the container through five complete circles.

Step 4: Using the container that is one-quarter full of water, swing it through five complete circles slowly; then repeat for another five complete circles using a faster speed.

Step 5: Using the one-quarter full container; check the effect of spinning the container through five complete circles in a big radius circle, then again for a small radius circle.

Step 6: Make and complete a chart like the one in the Observations section.

Observations

2. Copy and complete the following chart. Summarize your findings, by filling in the blanks with either the word *large* or *small*.

Mass of Container	Speed of Container	Radius of Circle	Force to Keep Container in circle
small	constant	constant	
large	constant	constant	
constant	slow	constant	
constant	fast	constant	
constant	constant	small	
constant	constant	large	

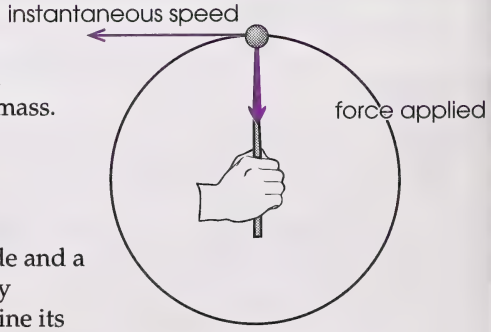
Analysis and Interpretation

3. Which required the most force on your part to keep spinning, the empty or partially full (more massive) container? According to Newton, why would this be so?

4. Which case, fast spin or slow spin, required you to hold the cord with more force?

Check your answers by turning to the Appendix, Section 2: Activity 1.

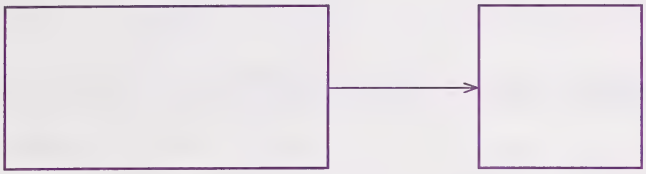
Did you notice that in each case, the force, large or small, was supplied by your hand? The diagram shows you the relation between the force and the instantaneous speed of the mass. Any force which causes a mass to move in a circular path is given a special name – **centripetal force**.



centripetal force – the force needed to change the linear motion of a mass into a circular motion – literally "centre-seeking" force

Forces are vectors, requiring both a magnitude and a direction. You now know the direction of any centripetal force, but how would you determine its magnitude? The key lies in Newton's description of forces and their magnitudes.

5. Complete the following by writing Newton's Second Law qualitatively (in words) then quantitatively (by giving the formula).



Newton's Second Law (Qualitative) | Newton's Second Law (Algebraic)

Check your answers by turning to the Appendix, Section 2: Activity 1.

In the previous investigation, speed and radius were found to be important factors influencing the centripetal force. Newton's Second Law does not include those factors. Any algebraic description of centripetal force must include speed and radius. But how?

VISIONS

To learn more about centripetal force and to see the mathematical relationship for centripetal force, read page 453 to the middle of page 454 and page 456 of *Visions 2*; then answer the following questions.

6. Which direction was the force acting when you swung the plastic container in the previous investigation?

7. Which direction would the plastic container fly if the cord broke while you were swinging it?

8. Complete the following to obtain an equation to describe centripetal force.

$$F_c = \frac{(\quad)(\quad)^2}{(\quad)}$$

(F_c = centripetal force in newtons (N).)

The formula in question 8 can be used to calculate the centripetal force of any object with a known mass moving in a circular path with a known radius with a known velocity. In the next activity you will confirm this formula through a simple experiment involving circular motion.

Check your answers by turning to the Appendix, Section 2: Activity 1.

Activity 2: Circular Motion Requires a Constant Force

Investigation: Confirming the Centripetal Force Formula

Follow the directions of this investigation carefully. Pay special attention to the required components, safety aspects, and applied science skills.

PATHWAYS

If you have access to laboratory facilities, do Part A. If you do not have access to laboratory facilities, do Part B.

Part A involves doing a laboratory investigation to confirm the formula for centripetal force.

Part B provides students without access to laboratory facilities with sample data for the experiment described. The data is used to complete the activity.

Science Skills

- ☐ A. Initiating
- ☑ B. Collecting
- ☑ C. Organizing
- ☑ D. Analysing
- ☑ E. Synthesizing
- ☑ F. Evaluating

Part A

Background Information

You will need to work with another person in this investigation. One person is needed to operate the stopwatch, while the other person swings the rubber stopper.

Materials

- hollow glass tube, 20 cm long, fire polished, and wrapped in masking tape to reinforce the glass
- 1.5 m of nylon cord, small enough to pass through the glass tube (e.g., 10 kg fishing line)
- two-hole stopper
- a laboratory mass (weight) set
- stopwatch
- masking tape
- triple beam balance or electronic balance
- metre stick

Procedure

Step 1: Attach one end of the nylon cord to the rubber stopper and feed the other end through the glass tube.

Step 2: Adjust the length of the cord such that the radius of the circle made (measured from the top of the tube to the centre of the stopper) by the stopper is 80.0 cm (0.800 m).

Step 3: Wrap a piece of masking tape around the cord immediately below the tube to make a flag.

Caution

Step 4: Attach a 100 g mass to the bottom end of the cord. Supporting the mass with one hand, spin the stopper around in a horizontal circle above your head. Make sure that you have a clear, unimpeded area to swing in. Ensure all observers stand back.

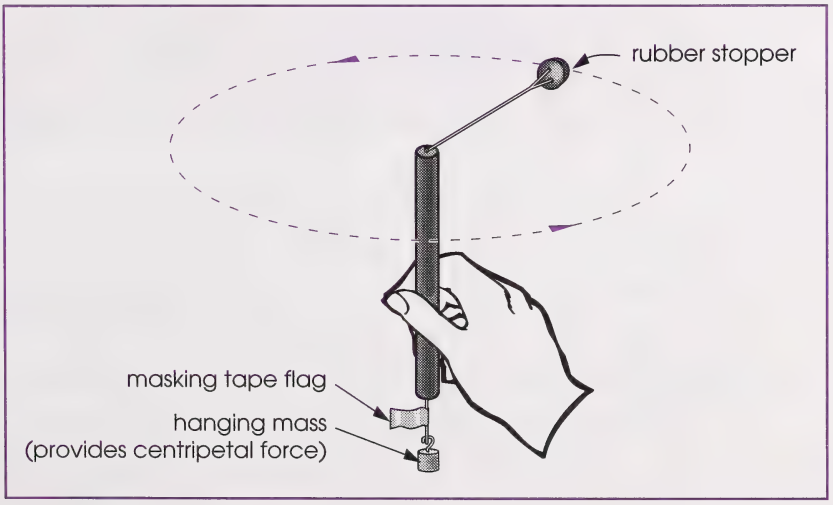
Step 5: Release the hanging mass and adjust the speed at which you are spinning the stopper so that the masking tape flag stays just below the bottom of the tube.

Step 6: Once you are able to maintain the flag at a steady position, have your helper measure the time required to complete 25 revolutions.

Step 7: Record this time in a chart like the one provided in the Observations section in Part B.

Step 8: Repeat steps 4 to 7 for hanging masses of 200 g, 300 g, 400 g, and 500 g.

Step 9: Measure and record the mass of the rubber stopper in the Observations section.



Do the Observations and the Analysis and Interpretation sections in Part B.

Science Skills

- ☐ A. Initiating
- ☐ B. Collecting
- ☑ C. Organizing
- ☑ D. Analysing
- ☑ E. Synthesizing
- ☑ F. Evaluating

Part B

Materials

- data results provided in the Procedure section
- pen or pencil
- paper
- calculator

Procedure

Read over Part A of this Investigation to familiarize yourself with the procedure involved; then use the following data, generated by a student performing the experiment to complete the remainder of this activity.

Hanging Mass (g)	100	200	300	400	500
Time for 25 Revolutions (s)	28.3	20.0	16.4	14.0	12.6

mass of stopper = 39.3 g

radius of circle = 0.800 m

Observations

1. radius of circle = _____ m mass of stopper = _____ kg

2. Copy and complete the following data chart.

Hanging Mass (kg)	Centripetal Force (N)	Time for 25 Revolutions (s)	Time for 1 Revolution (s)	Speed of Mass (m/s)	Speed^2 (m^2/s^2)
0.100	0.981	28.3	1.13	4.44	19.7
0.200		20.0			
0.300		16.4			
0.400		14.0			
0.500		12.6			

A sample of the calculations to complete the table is provided for the 100 g mass. Remember to carry all the digits in the calculator when proceeding from one step to the next where required.

- The hanging mass in kilograms is $100\,\text{g} \times \frac{1\,\text{kg}}{1000\,\text{g}} = 0.100\,\text{kg}$.

- The centripetal force in newtons (N) is hanging mass × acceleration due to gravity.

$$0.100\,\text{kg} \times 9.81\,\text{m/s}^2 = 0.981\,\text{kg} \bullet \text{m/s}^2$$
$$= 0.981\,\text{N} \text{ (3 significant digits)}$$

- The time for 25 revolutions in seconds is 28.3 s (from data).

- The time for 1 revolution in seconds is the time for 25 revolutions divided by 25.

$$\frac{28.3\,\text{s}}{25} = 1.132$$
$$= 1.13\,\text{s} \text{ (3 significant digits)}$$

- The speed of mass is circumference divided by time for one revolution.

$$\frac{2\pi r}{1.132\,\text{s}} = \frac{2(\pi)(0.800)}{1.132\,\text{s}}$$
$$= 4.4404$$
$$= 4.44\,\text{m/s} \text{ (3 significant digits)}$$

- $(\text{speed})^2 = (4.4404)^2$
$$= 19.7\,\text{m}^2/\text{s}^2 \text{ (3 significant digits)}$$

Complete the calculations for each of the remaining four masses.

3. Plot a graph of force versus $(\text{speed})^2$ on graph paper. Force is the dependent variable and goes on the vertical axis. Remember to follow all graphing rules.

Analysis and Interpretation

4. Does the graph produced indicate a direct relation between force and $(\text{speed})^2$ as would be predicted by the equation? Explain your answer.

$$F_c = \frac{mv^2}{r} \rightarrow F_c \propto v^2$$

5. What was the purpose in measuring the time for twenty-five revolutions?

6. Why was the stopper spun in a horizontal circle over your head? Why not in a vertical circle in front of you?

Check your answers by turning to the Appendix, Section 2: Activity 2.

End of Part A and Part B

Did you know that it is possible to modify the formula for centripetal force such that it doesn't use the speed of the revolving mass? This is quite useful since it is not always easy to measure speed.

$$F_c = \frac{mv^2}{r} \quad \text{and} \quad v = \frac{d}{t}$$

$$= \frac{2\pi r}{t} \left(\frac{\text{circumference}}{\text{time}} \right)$$

$$\text{thus, } F_c = \frac{m\left(\frac{2\pi r}{t}\right)^2}{r} \quad \left(\text{substituting for } v^2\right)$$

$$F_c = \frac{m\left(\frac{4\pi^2 r^2}{t^2}\right)}{r}$$

$$F_c = \frac{4\pi^2 m \cancel{r}^2}{\cancel{r} t^2}$$

$$F_c = \frac{4\pi^2 mr}{T^2} \quad \text{(It is normal to use } T \text{ in the formula for orbital time.)}$$

The following identifies each variable in the formula.

mass of object moving in the circle in kilograms ↓

Centripetal force in newtons → $F_c = \frac{4\pi^2 mr}{T^2}$ ← radius of the circular path in metres

↑ orbital period or time for one revolution in seconds

7. A comparison of the experimental orbital period and the theoretical orbital period is also a good way to check the validity of a formula. Complete the following chart using the measurements made in the previous investigation (see question 2) and the formula $T = \sqrt{\frac{4\pi^2 mr}{F_c}}$. This is derived from the formula $F_c = \frac{4\pi^2 mr}{T^2}$.

$$F_c = \frac{4\pi^2 mr}{T^2}$$

$$T^2 = \frac{4\pi^2 mr}{F_c} \quad \text{(Multiply each side by } T^2\text{, and divide each side by } F_c\text{.)}$$

$$T = \sqrt{\frac{4\pi^2 mr}{F_c}} \quad \text{(Take the square root of each side.)}$$

A sample calculation for the first row and the percent error follows the chart.

Centripetal Force (N)	Experimental Orbital Period (time for one revolution) (s)	Theoretical Orbital Period (s)	% error
0.981	1.13	1.12	0.893
1.96			

The following is a calculation to find the theoretical orbital period for a centripetal force of 0.981 N using the formula $T = \sqrt{\frac{4\pi^2 mr}{F_c}}$. The stopper mass and the radius from the previous investigation are used for m and r.

$$T = \sqrt{\frac{4(\pi)^2(0.0393)(0.800)}{0.981}} \quad \text{(Use the calculator value for } \pi\text{.)}$$

$$= 1.12 \text{ s} \quad \text{(3 significant digits)}$$

Calculate % error using the following formula.

$$\%\,\text{error} = \frac{|\text{Experimental Value} - \text{Theoretical Value}|}{\text{Theoretical Value}} \times 100$$

For the first row in the chart, % error is calculated as follows:

$$\%\,\text{error} = \frac{|1.13 - 1.12|}{1.12} \times 100$$
$$= \frac{0.01}{1.12} \times 100$$
$$= 0.893\% \text{ (3 significant digits)}$$

If you are not familiar with the expression *% error*, it is simply a means of comparing actual and expected values. Errors in an investigation are due to measurement errors. Many investigations may have about of 5% error.

8. Based on the average % error, would you conclude that the formula $F_c = \sqrt{\frac{4\pi^2 mr}{T^2}}$ is a suitable expression for centripetal force? Explain your answer. (Remember, you can account for about 5% difference in this method.)

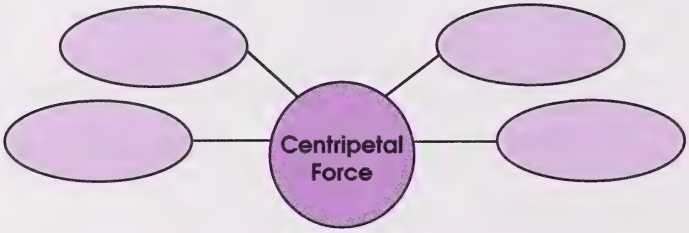
Check your answers by turning to the Appendix, Section 2: Activity 2.

In Activity 3 you confirmed the equation which describes circular motion. In the next activity you will solve problems using these formulas and demonstrate your understanding of circular motion.

Activity 3: Problem Solving with Circular Motion

In Activity 1 of this section you discovered the factors which describe circular motion.

1. Indicate the factors by which circular motion may be described in the following diagram.



Check your answers by turning to the Appendix, Section 2: Activity 3.

You also found an algebraic formula, which could be used to describe centripetal force. The investigation in Activity 2 confirmed that algebraic formula and introduced you to a modification of that formula.

In this activity you will have the chance to practise the use of algebraic formulas for both horizontal and vertical situations. You may see questions similar to the following.

Example:

A 400 g mass, tied to a string, is whirled in a circle of radius 50.0 cm at a speed of 20.0 m/s. What force must be applied to the string in order for this to occur?

The data is as follows:

$m = 400\ \text{g}$
$= 0.400\ \text{kg}$
$r = 50.0\ \text{cm}$
$= 0.500\ \text{m}$
$v = 20.0\ \text{m/s}$
$F_c = ?$

The solution is as follows:

$$F_c = \frac{mv^2}{r}$$
$$= \frac{(0.400\ \text{kg})(20.0\ \text{m/s})^2}{0.500\ \text{m}}$$
$$= 320\ \text{N}$$

The force that must be applied to the string is 320 N.

Since centripetal force may also be expressed in terms of period of orbit or revolution, it is likely that you may also see questions such as the following:

Example:

A traditional event in track and field is the hammer throw. In this event a 7.20 kg mass is attached to a chain to form the hammer. The thrower begins to rotate causing the mass to move in a horizontal circle. At the greatest rate of rotation, the hammer is released. Points are awarded for the greatest distance travelled by the hammer.

A competitor rotates the hammer in a horizontal circle of 2.10 m radius, at a rate of one revolution every 0.350 s. What is the centripetal force exerted on the hammer by the competitor?

The data is as follows:

$m = 7.20\ \text{kg}$
$r = 2.10\ \text{m}$
$T = 0.35\ \text{s}$
$F_c = ?$

The solution is as follows:

$$F_c = \frac{4\pi^2 mr}{T^2}$$
$$= \frac{4(\pi)^2(7.20\ \text{kg})(2.10\ \text{m})}{(0.350\ \text{s})^2}$$
$$= 4.87 \times 10^3\ \text{N} \quad \text{(3 significant digits)}$$

The centripetal force exerted on the hammer is about 4.87×10^3 N.

Of course it is entirely possible that you may be required to solve for some factor other than centripetal force. In such a situation you must solve for one of the other variables in the formula.

Example:

A 550 N force must be applied to a 400 g mass to cause to move in a circular path of radius 1.20 m.

a. What is the speed at which the mass is moving?

b. How much time is required for the mass to complete one revolution?

The data is as follows:

$F_c = 550\ \text{N}$ $\quad r = 1.20\ \text{m}$

$m = 400\ \text{g}$ $\quad v = ?$

$= 0.400\ \text{kg}$ $\quad T = ?$

The solutions are as follows:

a. $F_c = \dfrac{mv^2}{r}$

$F_c r = mv^2$

$\dfrac{F_c r}{m} = v^2$

$v = \sqrt{\dfrac{F_c r}{m}}$

$= \sqrt{\dfrac{(550\ \text{N})(1.20\ \text{m})}{0.400\ \text{kg}}}$

$= 40.6\ \text{m/s}$

(3 significant digits)

b. $F_c = \dfrac{4\pi^2 mr}{T^2}$

$F_c T^2 = 4\pi^2 mr$

$T^2 = \dfrac{4\pi^2 mr}{F_c}$

$T = \sqrt{\dfrac{4\pi^2 mr}{F_c}}$

$= \sqrt{\dfrac{4\pi^2 (0.400\ \text{kg})(1.20\ \text{m})}{550\ \text{N}}}$

$= 0.186\ \text{s}$

(3 significant digits)

VISIONS

Carefully read the section entitled Where There Is an Unbalanced Force, There Is Acceleration on pages 458 and 459 of *Visions 2*. From your reading you should note that it is possible to focus on acceleration alone if needed. The following example illustrates how to calculate centripetal acceleration.

Example:

What is the centripetal acceleration of a sprinter who rounds a turn on a track with a radius of 30.0 m at 11.0 m/s?

The data is as follows:

$v = 11.0\ \text{m/s}$
$r = 30.0\ \text{m}$
$a = ?$

The solution is as follows:

$$a = \frac{v^2}{r}$$
$$= \frac{(11.0\ \text{m/s})^2}{30.0\ \text{m}}$$
$$= 4.03\ \text{m/s}^2 \quad \text{(3 significant digits)}$$

The following questions will allow you to practise your skills at solving problems relating to circular motion.

2. A 1300 kg car is turning a corner in a circular arc with radius equal to 8.00 m at a velocity of 5.00 m/s. What minimum centripetal force, supplied by the pavement on the tires, is needed to hold the car in this circular path?

3. A popular playground apparatus is the merry-go-round. This apparatus consists of a flat disk, with attached handles, that is rotated. A 40.0 kg child is on edge of the 1.50 m radius disk when it is being rotated at a rate of 2.00 s per revolution. What is the minimum force the child needs to exert in order to stay on the ride?

ISIONS

4. Answer at least one of questions 1 and 2 on pages 457 and 458 of *Visions* 2. Question 1 refers back to example 2 of the Practise Problems on page 457.

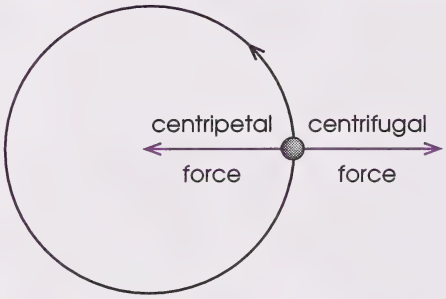
Check your answers by turning to the Appendix, Section 2: Activity 3.

If you have ever played on a merry-go-round, you will be familiar with the feeling that something is pulling you off of the ride. A similar feeling will occur as you round a curve or corner while riding in a car. It feels as if something is pulling you – afterall, you must exert a force to counteract the effect.

ntrifugal
rce – a
action effect
up by a
ntripetal force,
rally "centre-
eing" effect

The name given to this apparent pull is **centrifugal force**. The term is actually somewhat of a misconception. The reason this apparent force is considered a misconception or a fictitious force is because it exists only while the rotation is occuring. Your textbook calls this apparent pull a *centrifugal effect*. The apparent outward force is a result of two aspects:

- Direction of the force results from the tendency of a mass to move in a straight line.
- Magnitude of the force results from Newton's Third Law – as the centripetal force increases, there will be an equal but opposite force created.



Since the forces are equal in magnitude and opposite in direction, the mass remains in a stable orbit.

Although centrifugal force is not a true force, it does help to explain observations as a result of circular motion such as the feeling that something is pulling you as you round a curve in a car as well as how a centrifuge works.

VISIONS

For some excellent examples of technology utilizing the effects of centripetal acceleration, carefully read Section 12.2 entitled Using Centripetal Forces on pages 462 to 466 of *Visions 2*. Be sure to pay particular attention to the diagrams in this section (particularly Figure 12.4 on page 464).

5. Explain how a centrifuge works to separate various components of a substance.

6. What is an analytical centrifuge and what is it used for?

7. Answer Checkpoint question 1 on page 466 of your textbook.

Check your answers by turning to the Appendix, Section 2: Activity 3.

Remember centrifugal force is a result of a centripetal force and should really be named as an effect and not a force.

In this activity you have practised solving problems involving circular motion. You have also analysed some situations involving the effects of circular motion.

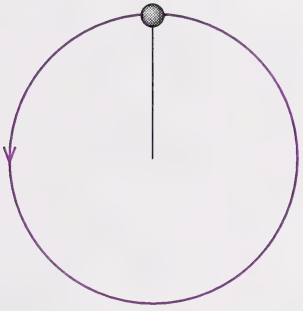
Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

Circular motion requires certain conditions to be fulfilled since the normal motion of any mass is to continue in a straight line at a constant speed. Any change in that motion requires the application of a force; and since objects in circular motion continually change direction, there must be a continuous force exerted.

1. The following diagram indicates a mass rotating in a circular path. Sketch in and label vectors to show the direction of the centripetal force affecting the ball and instantaneous speed of the ball.



2. Complete the following statements with the word **increase** or **decrease** to make the statement true.

   a. An increase in the mass of an object requires an _____ in the amount of force applied to keep the mass moving in a circle.

   b. As the radius of an object's circular path increases, the amount of force needed to hold the object in that circle will _____.

   c. As the instantaneous speed of the object increases, the centripetal force must _____ to maintain the same radius.

3. Another student claims that it is impossible to be accelerating when you are travelling at a constant velocity. Explain to this student how it is possible to accelerate even though you are travelling at a velocity that does not change.

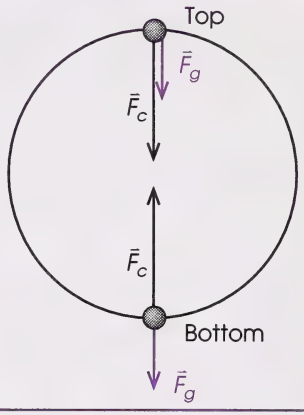
4. In a mass spectrograph, the path of an electrically charged particle is bent into a circle by a force caused by a magnetic field. An electron of mass 9.11×10^{-31} kg, travelling at 2.50×10^{4} m/s, is bent into a circular path of 20.0 cm radius. What is the force supplied by the magnetic field?

Check your answers by turning to the Appendix, Section 2: Extra Help.

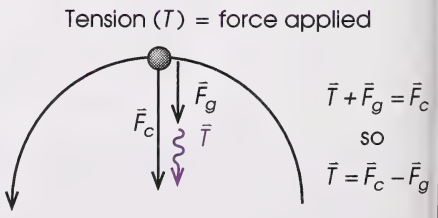
Enrichment

Recall in the investigation in Activity 2 of this section you twirled the stopper in a horizontal plane rather than in a vertical plane. The reason given was that gravity affects the centripetal force in the vertical plane. The following is a further explanation of how gravity affects centripetal force when an object is swung in a vertical plane.

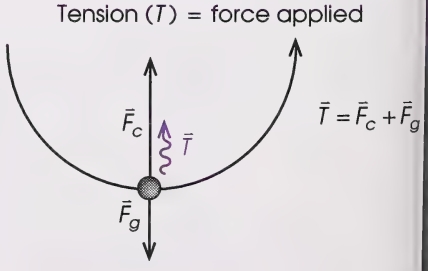
You may be asking yourself why all of the situations seen so far have stressed or implied the use of a horizontal circular motion. The reason is that vertical circular motions must take into account the force of gravity.



If the circular motion is vertical, there will be a difference between the upper half and lower half of the swing. For example, as the swing moves from the centre up, the force of gravity will supply some of the needed centripetal force, with the maximum amount being supplied at the top. Thus, the force applied to the string will not need to be as much.

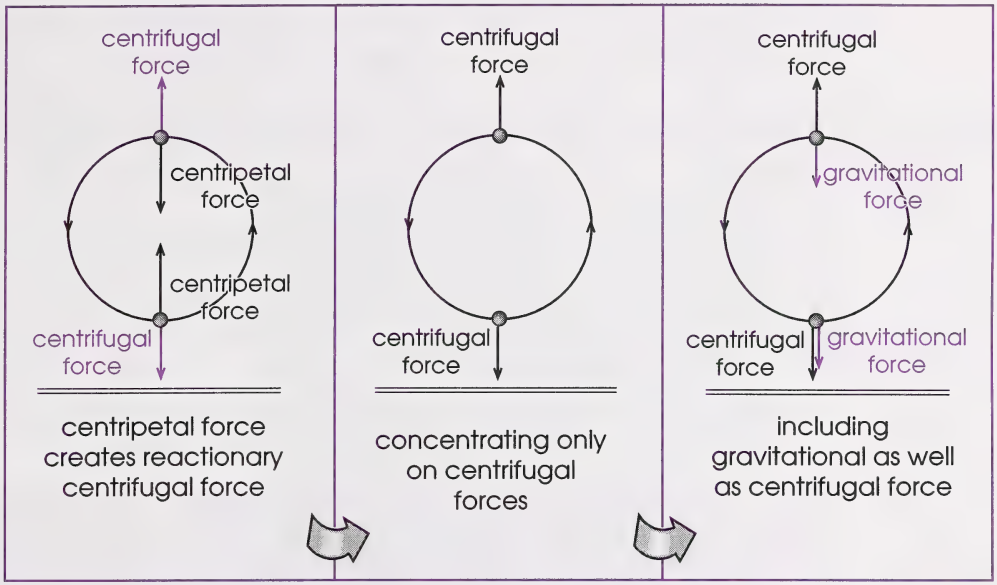


In the bottom half of the swing this would not be true since the gravitational force will act to counteract the centripetal force. The maximum force supplied by gravity will be at the bottom of the swing. Therefore, the force applied to the string must supply centripetal force as well as negate the force of gravity.



Your last reading in Activity 3 of this section mentioned the difficulties pilots experience with greater speeds and maneuverability. Those problems are good examples of an idea introduced in Activity 3. That is the idea that forces other than centripetal forces must be considered.

For example, if you were to focus your attention on the centrifugal reaction force for a vertical loop, you might notice the following.



Notice how gravity tends to negate the centrifugal effect at the top of a vertical loop and augment the effect at the bottom. That is what causes the blood to pool in the legs and abdomen resulting in blackouts.

Top of Loop $F_{net} = F_c - F_g$

Bottom of Loop $F_{net} = F_c + F_g$

An airplane in a turn experiences a centripetal force. The passengers, or pilot inside, will have a tendency to continue in a straight line. Centrifugal force could be considered to be the force that the pilot exerts on the plane, while centripetal force is exerted by the plane on the pilot. The following is a summary of how a pilot might experience a blackout.

The airplane turns, **but** the pilot is still free to move (pilot continues to move in a straight line).

↓

The pilot contacts the seat and is forced by the plane to turn, **but** the blood is still free to move (it continues in a straight line to pool in the lower extremities).

↓

A lack of blood (and oxygen supply) to the brain produces a blackout.

The questions that follow may help you to clarify this concept in your mind.

1. A jet is travelling at approximately Mach 1.3 (440 m/s) when it pulls out at the bottom of a dive. The radius of the curve followed in the pull out is 2.00 km. What is the net force acting on the 90.0 kg pilot?

2. A rollercoaster is set up such that a feeling of weightlessness is experienced at the top of a hill. What is the speed necessary to do this for a hill with a radius of curvature of 10.0 m? (Remember: F_{net} must equal zero to be weightless.)

In a cyclotron (circular particle accelerator), charged particles are forced to travel in circular paths while being accelerated to very high speeds. The magnetic force which provides the centripetal force must be constantly adjusted to prevent the radius from changing while the particle is accelerating. Once the particle reaches a constant velocity, the magnetic force remains constant.

3. What magnetic force is required to hold an electron in a circle with a 10.0 cm radius, where the electron completes 1680 revolutions every second?

Check your answers by turning to the Appendix, Section 2: Enrichment.

Conclusion

In this section you have looked at the concept of circular motion. You derived algebraic expressions to describe circular motion, and you have looked at some practical aspects of that motion. In Section 3 you will apply the concept of circular motion to the orbital motion of satellites and celestial bodies.

ASSIGNMENT

Turn to your Assignment Booklet and do the assignment for Section 2.

Section

3 As the World Turns

As the full moon rises over the horizon, the early evening stars begin to form their familiar patterns. There, appearing above you in the sky, is the first constellation you learned to recognize – the Big Dipper. As the evening progresses, the stars move in their slow, characteristic areas across the sky. Isn't it nice to know that some things in this world don't change?

Wait a second! Why do the stars and other heavenly objects move in arcs across the sky? Or do they?

In this section you will be introduced to the work of several historical figures upon which the science of orbital mechanics is based. You will then use your knowledge of circular motion from Section 2 to describe and predict satellite motion. Finally, you will apply your knowledge to the topic of rotating space stations.

Activity 1: Motion of the Planets and Other Celestial Bodies

One of the most striking aspects of the world is its cyclical nature. The seasons repeat themselves winter to summer and back again. The sun and moon rise, move across the sky in arcs, and set in a regular, predictable fashion. Even the stars in the sky seem to move in circles.

But do they? This is not a trivial question! It wasn't really all that long ago when asking such a question would have meant torture and possibly even death!

VISIONS

For an introduction to some of the history and historical figures involved with descriptions of the universe, read page 470 to the middle of page 472 of *Visions 2*; then answer the next two questions.

1. Using the information from the textbook, match the following scientists and terms with their respective statements.

   - epicycle
   - Ptolemy
   - Tycho Brahe
   - Kepler
   - Copernicus
   - Newton

   a. Planets move in elliptical orbits about the sun.

   b. The sun is the centre of the universe.

   c. The Earth is the centre of the universe, the sun orbits the Earth, and the planets orbit the sun.

   d. The Earth at the centre and the planets move around the Earth as well as travel around in their own small circular path.

   e. Gravity provides the force which allows planets to orbit the sun.

   f. A circular motion about a point which revolves in a circle around another point.

A number of historical figures were introduced in the reading on pages 470 to 472 of your textbook. In particular, the work of Tycho Brahe and Johannes Kepler was introduced.

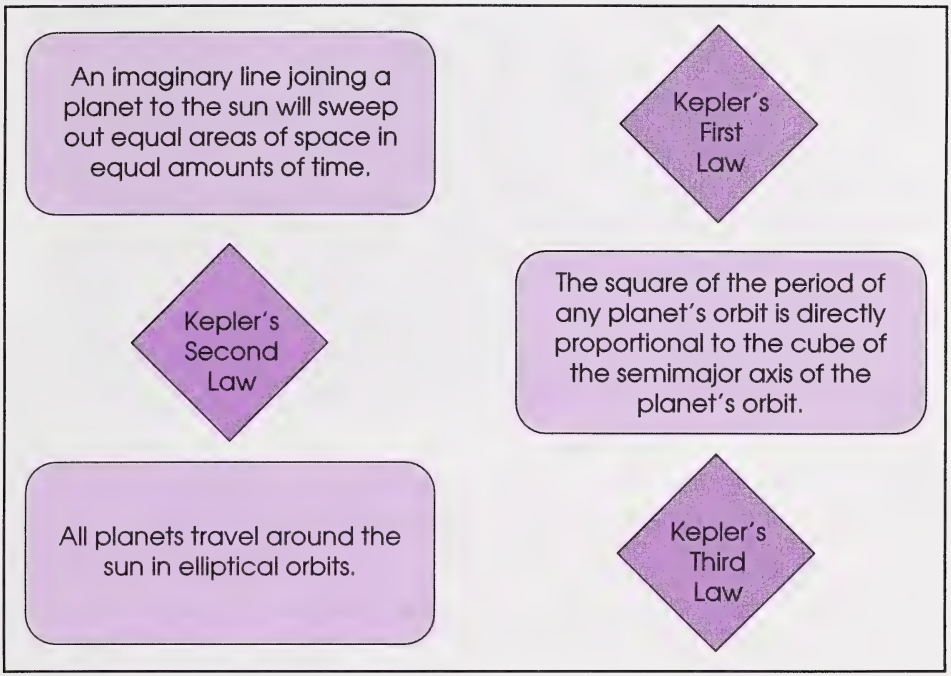
2. Although Tycho Brahe did produce a model of the universe, he is not known for the success or failure of his model as are other historical figures. What was the real value of Brahe's work?

Check your answers by turning to the Appendix, Section 3: Activity 1.

VISIONS

For further information related to Kepler's laws, carefully read the section Kepler's Laws Mathematically Describe The Motion of Planets on pages 472 to 474 of *Visions* 2.

3. Three simplified statements of Kepler's discoveries are found in the following diagram. Match the statements to the appropriate label.


An imaginary line joining a planet to the sun will sweep out equal areas of space in equal amounts of time.
Kepler's First Law
Kepler's Second Law
The square of the period of any planet's orbit is directly proportional to the cube of the semimajor axis of the planet's orbit.
All planets travel around the sun in elliptical orbits.
Kepler's Third Law

4. Refer to Figure 12.10 on page 473 of the textbook. How does the speed of a planet as it travels from A to B compare to its speed as it travels from C to D?

Kepler's laws, especially his third law, greatly influenced the thinking of Isaac Newton. According to accounts written by Newton, Kepler's Third Law allowed Newton to deduce the way in which the force of gravity varies over distance.

5. Kepler's Third Law can be mathematically expressed. Give the mathematical expression and explain the meaning of the symbols in words.

Check your answers by turning to the Appendix, Section 3: Activity 1.

According to writings left by Newton, an apple falling to the ground led him to suspect that the force of gravity acted on any object near the Earth, including the moon. To explain why the moon didn't fall straight towards the Earth, Newton assumed that the moon's orbital velocity caused the moon to fall around the Earth.

By comparing Kepler's Third Law with the restrictions of circular motion, Newton was able to determine that the force of gravity depends upon several factors, such that

$$\text{force of gravity} \propto \frac{1}{(\text{radius})^2}$$
$$\propto \text{mass}_{(\text{moon})}$$
$$\propto \text{mass}_{(\text{Earth})}$$

In a more mathematical form,

$$F_g \propto \frac{m_{\text{moon}} m_{\text{Earth}}}{r^2}$$

Mathematically it is possible to remove the proportionality by adding a constant of proportion, in this case a value, G.

$$F_g = \frac{G m_{\text{moon}} m_{\text{Earth}}}{r^2},$$

where G = gravitational constant (constant of proportion)

This gravitational constant (G) was later measured experimentally to be

$$G = 6.67 \times 10^{-11}\ \text{N} \bullet \text{m}^2 / \text{kg}^2$$

Written as a decimal, $G = 0.000\,000\,000\,0667\ \text{N} \bullet \text{m}^2 / \text{kg}^2$. This is a very small value.

You may wish to note that Newton made the intuitive leap that this relation could describe the force of gravity between any two masses. Referring to this relation as the Law of Universal Gravitation, Newton stated that

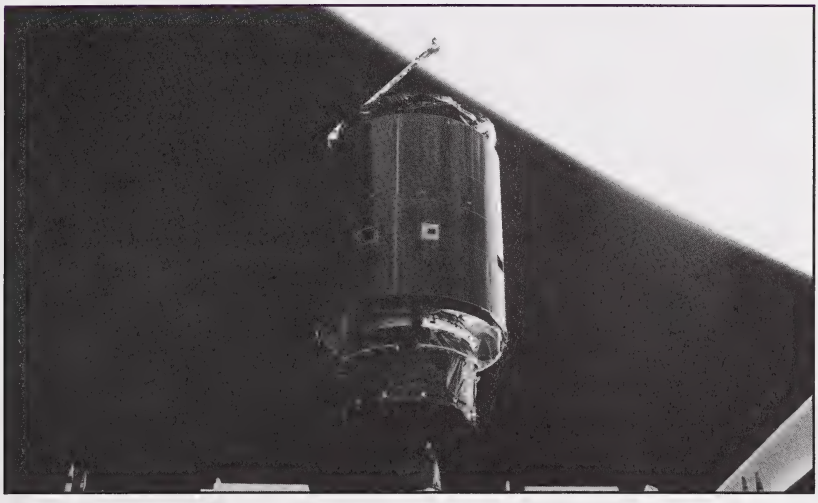
$$F_g = \frac{G m_1 m_2}{r^2}$$

r represents the distance between the centres of mass of the objects involved. You should recall this formula from Module 7.

6. Describe a method by which you could measure the value of the gravitational constant G. Specify the procedure you would use. (Hint: Rearrange the relation for the Law of Universal Gravitation and solve for G.)

Check your answers by turning to the Appendix, Section 3: Activity 1.

Activity 2: Understanding Satellite Motion



NASA

The launch of the first artificial satellite, *Sputnik*, in 1957 produced a flurry of activity and set off what has been called the "Space Race." Today the aerospace industry is a multi-billion dollar endeavour, employing hundreds of thousands of people worldwide.

Telecommunications satellites, weather satellites, and the *Hubble* space telescope are only some of the more useful and practical offshoots of the "Space Race." The communications satellite in the previous photograph is being released from the cargo bay of the space shuttle *Endeavor*.

In this activity you will analyse qualitatively how satellites orbit the Earth. Satellite motion can be considered to be essentially a circular motion.

1. What factors determine the circular motion of an object?

Check your answers by turning to the Appendix, Section 3: Activity 2.

In Section 2 you performed an experiment in which an object was made to travel in a circular path. In that experiment, a string connected to the object was an essential component of the activity.

2. What aspect of circular motion did the string supply?

3. You will notice that there isn't a string connecting the Earth to the moon. What would cause the moon to move in a circular path about the Earth?

Check your answers by turning to the Appendix, Section 3: Activity 2.

VISIONS

Read Section 12.3 entitled Gravitational Force as a Centripetal Force on pages 466 to 470 of *Visions 2*.

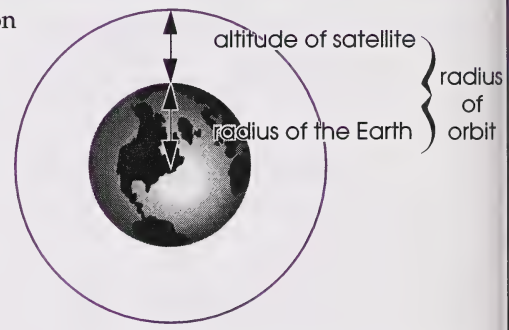
4. According to your reading, how is the centripetal force related to the gravitational force on a satellite? Express your answer in words.

5. In example 2 of the Practice Problems on page 469 of *Visions 2*, the radius of the Earth was added to the altitude of the satellite. Explain why this was necessary.

Check your answers by turning to the Appendix, Section 3: Activity 2.

radius of orbit – the distance of a satellite from the centre of the body it is orbiting

The value discussed in the previous question is called the **radius of orbit**. The following diagram illustrates the way in which the radius of orbit of a satellite is found.



For communications purposes it is most useful to have a satellite which can always be found at the same point in the sky. This eliminates problems with tracking the satellite.

VISIONS

For more information relating to this topic, carefully read the section entitled Artificial Satellites Obey Kepler's Laws on pages 475 to 478 of *Visions 2*. Study the sample calculations carefully.

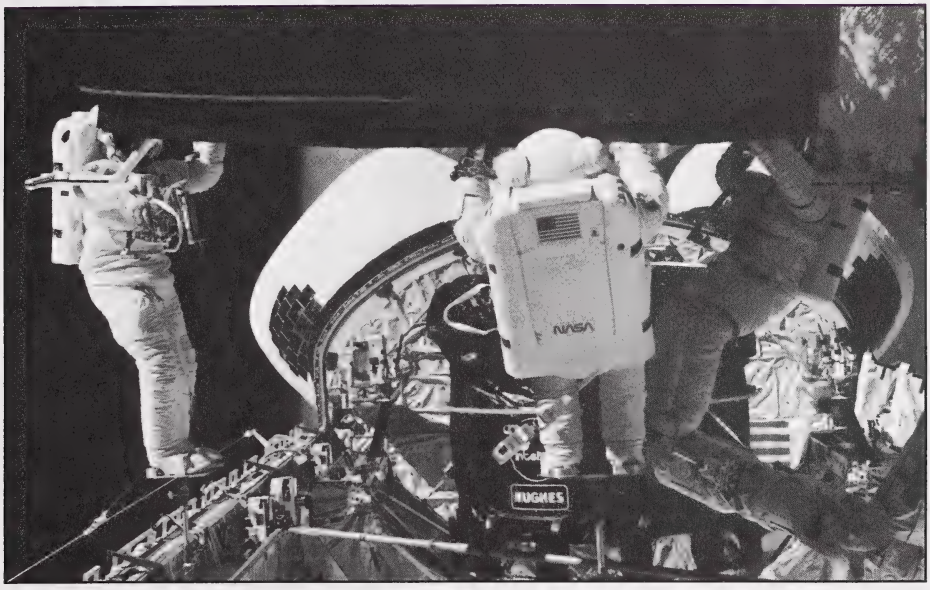
6. Explain the problems that arise when scientists track an orbiting satellite.

7. a. Why is the word *geostationary* a good description of the satellite described in the sample calculation?

   b. Remote sensing satellites are not placed into a geostationary orbit purposefully. Why?

Check your answers by turning to the Appendix, Section 3: Activity 2.

Activity 3: Life in Space



NASA

Science fiction writers have found that speculations on the living and working conditions within an orbiting space station have provided a steady source of material for their writing. However, science fiction does become science fact. In the early 1990s the United States began construction of the manned orbiting space station *Freedom*.

The astronauts in the previous photograph are not working on a space station but they are working in space. In this case they are capturing a satellite, attaching it to a booster, and deploying it to a new orbit. Have you ever wondered what the fascination is with life aboard a space station? Have you wondered why the United States would spend billions of dollars in research and is proposing to spend billions more just to construct a space station? After all, with that kind of money, there must be some purpose and some use to such a station.

1. What advantage is there to a manned orbiting satellite? List three major uses, or advantages, for such a satellite?

Check your answers by turning to the Appendix, Section 3: Activity 3.

The space station *Freedom* is really an international endeavour, since at least some of the design, mechanical systems, or components originate in countries other than the United States. Canada has contributed a great deal to the design and technology of orbiting satellites. Carefully read the section entitled Canada and the Space Program on pages 480 and 481 of *Visions 2*.

2. Since the launch of the *Anik A-1* satellite in 1972, Canada has been a world leader in satellite communications. RADARSAT, which was designed and developed in Canada, is a good example of the usefulness and productivity of Canada's Space Program. What is the RADARSAT used for?

3. The "Canadarm," designed and built in Canada, has enjoyed a high profile in many of the shuttle missions flown by NASA. What is the Canadarm, and what is it used for?

4. What are some of the experiments performed by the first Canadian astronauts?

Check your answers by turning to the Appendix, Section 3: Activity 3.

Carefully read the section entitled Weightlessness Affects Living and Non-living Systems on pages 481 to 484 of *Visions 2*.

5. An integral part of training to become an astronaut involves getting used to working under weightless (microgravity) conditions. The airplane referred to in your reading has been unofficially dubbed the "VOMIT COMET."

   a. Describe how the flight trajectory of the plane could produce a brief weightlessness.

   b. Why is this airplane named the "VOMIT COMET?"

6. Make a chart listing the advantages and disadvantages of a space station which features weightless conditions.

Check your answers by turning to the Appendix, Section 3: Activity 3.

Science Skills

- ☐ A. Initiating
- ☑ B. Collecting
- ☑ C. Organizing
- ☑ D. Analysing
- ☑ E. Synthesizing
- ☑ F. Evaluating

PATHWAYS

If you are working with a group of students, do Part A. If you are working alone, do Part B.

Part A

VISIONS

Complete Activity 12.3 entitled Considering Rotating Space Stations on pages 484 and 485 of *Visions* 2.

Part B

Read the Procedure from Activity 12.3 on page 484 of *Visions* 2. Try to find as much information as you can regarding the research and manufacturing planned for completion in space. (Groups two and three)

7. Answer the questions posed for Groups two and three in the Procedure.

8. Imagine yourself to be a representative of each of the following groups. Fill in the dialogue bubbles as you would expect a member of each group to respond to the question of whether a rotating space station should be built.

   - Ecologist
   - Military
   - Business Executive
   - Research Scientist

Check your answers by turning to the Appendix, Section 3: Activity 3.

End of Part A and Part B

9. From a purely human point of view, space forms a hostile environment. The process of reaching space requires riding atop of what amounts to a very large bomb. Remember the *Challenger* disaster? Are the risks to human life worth it? Can the cost be justified? List the benefits and risks of the space program. Decide whether you feel the space program is valuable or not.

One of the major medical risks to astronauts is the loss of bone calcium under weightless conditions. Proposals to eliminate this risk centre on the use of a rotating space station.

10. Using your knowledge of circular motion and centripetal force from Section 2, describe how a rotating space station could create an artificial gravity.

Check your answers by turning to the Appendix, Section 3: Activity 3.

While rotating a space station solves one problem, it introduces another. How would you dock with a rotating station? This is like asking how do you get onto a moving merry-go-round. Even worse, not only is the space station rotating, it is also revolving around the Earth and so keeps moving relative to where you are. This would be like trying to get on a moving merry-go-round which is mounted on a truck driving past you. So how would you dock with a rotating space station? The first part of the answer is simple, in theory. Be at the same place at the same time. The second part presents a few technical problems in the design of the satellite.

11. How would a shuttle dock at a rotating space station? Prepare a sketch to illustrate a design for a rotating space station which could allow a shuttle to dock without a "crack the whip" effect. Outline how your design would accomplish this task.

Check your answers by turning to the Appendix, Section 3: Activity 3.

Of course the docking problem is entirely academic unless you can get to the orbiting station. To be in the same place at the same time requires very precise calculations. You must be able to plot a trajectory which allows you to intercept the space station. You cannot just get to the same orbital radius and then catch up to, or wait for, the station as it moves in the same orbit. Why not? Consider the following scenario.

You are in orbit 1000 km above the Earth's surface. Ahead in the same orbit is your destination space station.

12. Fill in the blanks with the appropriate term.

The pilot of your shuttle fires the nose thrusters (retro rockets) causing the shuttle to _____ (accelerate/decelerate). The change in speed which results causes an _____ (increase/decrease) in the orbital radius of the shuttle. Since the shuttle is in a _____ (higher/lower) orbit it will have a different orbital period and in effect will be travelling _____ (faster/slower) than the station. The pilot would pull ahead of the station and then fire the tail thrusters to reverse the changes and thus arrive at the station.

Check your answers by turning to the Appendix, Section 3: Activity 3.

Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a good understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

Observations of the regular motion of the stars, the moon, and the sun across the sky allowed early astronomers to devise models to explain those regular motions.

1. Do textbook question 1 on page 486 of *Visions* 2.

2. When astronomers hear the name Copernicus they almost automatically think of a heliocentric model of the universe. The name Ptolemy brings to mind visions of complicated patterns of rotating circles on circles. What would the name Tycho Brahe bring to mind for astonomers?

3. Sketch and label a diagram to illustrate each of Kepler's three laws of planetary motion.

Check your answers by turning to the Appendix, Section 3: Extra Help.

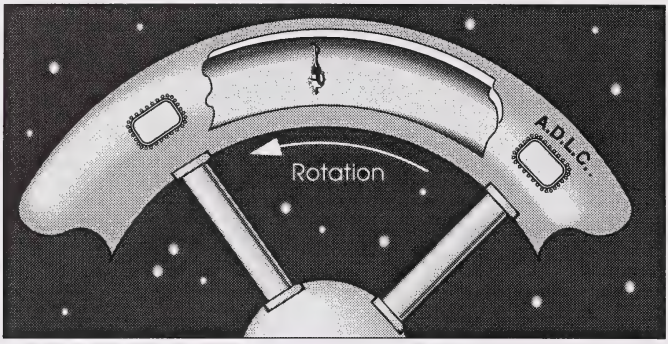
The force of gravity supplies the centripetal force for objects in circular motion (orbit) about planets and stars. For any object in a stable circular orbit, the force of gravity must equal the centripetal force.

4. What does this infer about the speed and distance of a satellite from the Earth.

Check your answers by turning to the Appendix, Section 3: Extra Help.

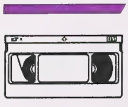
Satellites, although attracted towards the mass they orbit, are essentially falling around that mass. People and objects within such a satellite appear weightless because they are falling at the same rate. Although weightless conditions present several advantages, serious medical problems are associated with extended periods of weightlessness. Rotating the satellite presents a method by which an artificial sensation of gravity may be created.

5. a. Sketch and label the forces which are acting on the person shown in the diagram.



b. Describe how a rotating satellite can cause a sensation of gravity.

Check your answers by turning to the Appendix, Section 3: Extra Help.



You may watch the video entitled *Apple and the Moon*, from the *Mechanical Universe* series, ACCESS Network for a review of Kepler's laws and the concepts relating to circular and planetary motion. You may be able to obtain this video through your school or local library.

Enrichment

One of the most profound differences between ground-based life and orbital life, as experienced by astronauts, is weightlessness. You are probably not aware of just how pervasive the force of gravity is to your life experiences. Every action and every event in your formative years is determined by the way in which objects behave in Earth's gravitational field. In free fall, the effect of gravity is no longer consistent with your normal experience. Any actions taken will not occur normally. Any machinery designed for use at the Earth's surface will not operate normally.

Make a list of the changes to daily living and devices that would have to be made due to the conditions produced by weightlessness. Suggest possible solutions to the problems created by those changes, which do not involve rotating the ship.

For example, how would you shower in weightlessness?

Check your answers by turning to the Appendix, Section 3: Enrichment.

Conclusion

In this section you have looked at the history of astronomical models of the universe, as well as the concepts of planetary and satellite motion. You also saw how these concepts can relate to the development of a manned orbiting space station.

ASSIGNMENT

Turn to your Assignment Booklet and do the assignment for Section 3.

MODULE SUMMARY

In collisions, objects exert a force on each other over a period of time. There is an exchange of momentum between the objects. Momentum is defined as mass times velocity. You can measure mass and velocity of objects in a collision and calculate changes in momentum. A change in momentum can be related to impulse, which is defined as a force applied over time. Impulse is the push on an object by the applied force.

Since the amount of time is important in a collision, this concept can be used to design safety equipment. Car bumpers and steering wheels are made collapsible so that the force of a collision occurs over a longer period of time. When the total impulse $\left(\bar{F}\Delta t\right)$ remains the same and the change in time $\left(\Delta t\right)$ is larger, then the force $\left(\bar{F}\right)$ is smaller.

Circular motion involves a force. Since the tendency of an object in motion is to remain in a straight line, a constant force is required to maintain circular motion. That force is called centripetal force and may be supplied by the tension of a string, as in a swinging object, or by gravity, as in the moon orbiting the Earth or a satellite orbiting the Earth. Newton's laws have enabled scientists to put satellites into orbit and send humans to the moon and bring them back. A direct relationship exists between the conservation of momentum, Newton's laws of motion, and Kepler's laws.

This is the final module in the Science 20 course. After you complete the assignment for this module and write a final test, you will have completed the Science 20 course. Congratulations!

COURSE SURVEY FOR SCIENCE 20

Please evaluate this course and return this survey when you have completed your last module assignment. This is a course designed in a new distance-learning format, so we are interested in your responses. Your constructive comments will be greatly appreciated, as future course revisions can then incorporate any necessary improvements.

Name _____ Course _____

Address _____ Age ❑ under 19 ❑ 19 to 40 ❑ over 40

_____ File No. _____

_____ Date _____

Design

1. This course contains a series of module booklets. Do you like the idea of separate booklets?

_____

_____

2. Have you ever enrolled in a correspondence course that arrived as one large volume?

❑ Yes ❑ No If yes, which style do you prefer?

_____

_____

3. The module booklets contained a variety of self-assessed activities. Did you find it helpful to be able to check your work and have immediate feedback?

❑ Yes ❑ No If yes, explain.

_____

_____

4. Were the questions and directions easy to understand?

❑ Yes ❑ No If no, explain.

_____

_____

5. Each section contains Follow-up Activities. Which type of follow-up activity did you choose?

   ❑ mainly Extra Help
   ❑ mainly Enrichment
   ❑ a variety
   ❑ none

   Did you find these activities beneficial?

   ❑ Yes ❑ No If no, explain.

   _____

   _____

6. Did you understand what was expected in the section assignments?

   ❑ Yes ❑ No If no, explain.

   _____

   _____

7. The course materials were designed to be completed by students working independently at a distance. Were you always aware of what you had to do?

   ❑ Yes ❑ No If no, provide details.

   _____

   _____

8. Suggestions for audiocassette and videocassette activities may have been included in the course. Did you make use of these media options?

   ❑ Yes ❑ No Comment on the lines below.

   _____

   _____

Course Content

1. Was enough detailed information provided to help you learn the expected skills and ojectives?

   ❑ Yes ❑ No Comment on the lines below.

   _____

   _____

2. Did you find the work load reasonable?

❑ Yes ❑ No If no, explain.

_____

_____

3. Did you have any difficulty with the reading level?

❑ Yes ❑ No Please comment.

_____

_____

4. How would you assess your general reading level?

❑ poor reader ❑ average reader ❑ good reader

5. Was the material presented clearly and with sufficient depth?

❑ Yes ❑ No If no, explain.

_____

_____

General

1. What did you like least about the course?

_____

_____

2. What did you like most about the course?

_____

_____

Additional Comments

_____

_____

_____

Only students enrolled with the Alberta Distance Learning Centre need to complete the remaining questions.

1. Did you contact the Alberta Distance Learning Centre for help or information while doing your course?

   ❑ Yes ❑ No If yes, approximately how many times? _____

   Did you find the staff helpful?

   ❑ Yes ❑ No If no, explain.

   _____

   _____

2. Were you able to fax any of your assignment response pages?

   ❑ Yes ❑ No If yes, comment on the value of being able to do this.

   _____

   _____

3. If you were mailing your assignment response pages, how long was it taking for their return?

   _____

   _____

4. Was the feedback you received from your correspondence teacher helpful?

   ❑ Yes ❑ No Please comment.

   _____

   _____

   _____

   _____

Thanks for taking the time to complete this survey. Your feedback is important to us. Please return this survey with your last module assignment.

Instructional Design and Development
Alberta Distance Learning Centre
Box 4000
Barrhead, Alberta
T0G 2P0

Appendix

Glossary

Suggested Answers

Glossary

centrifugal force: a reaction effect set up by a centripetal force, literally "centre-fleeing" effect

centripetal force: the force needed to change the linear motion of a mass into a circular motion – literally "centre-seeking" force

impulse: the product of force applied and time of application

isolated system: a group of objects that experience a net force of zero due to forces outside the group

momentum: the product of mass and velocity

radius of orbit: the distance of a satellite from the centre of the body it is orbiting

Suggested Answers

Section 1: Activity 1

1. The graph is easier because it consists of straight lines and regular geometric areas. Curved lines require more complex mathematical formulas and techniques to describe.

2.

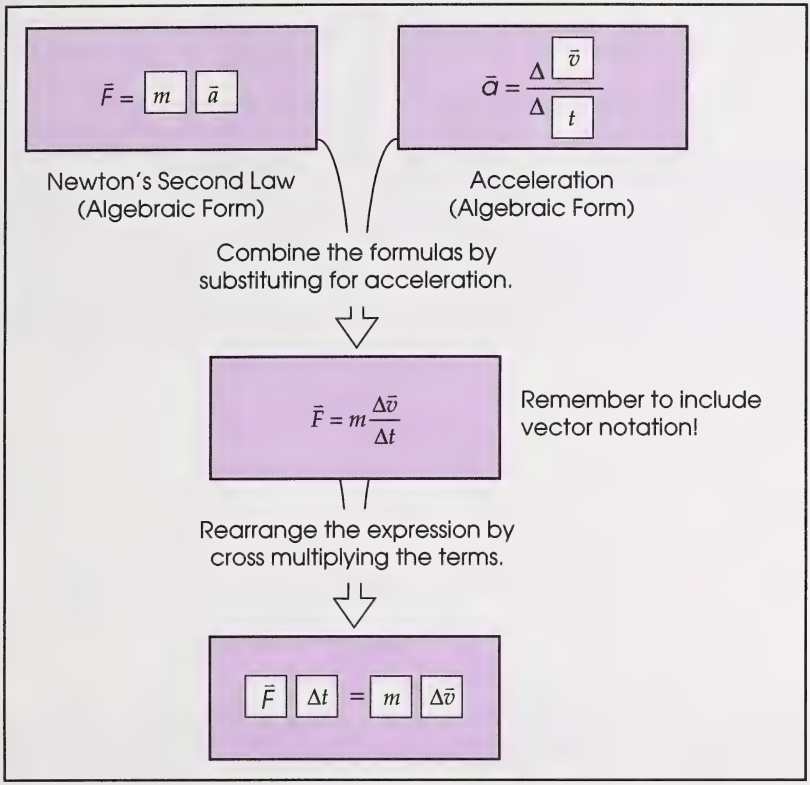
Type of Graph	Function	Quantity Represented
distance versus time	slope	speed
	area	
velocity versus time	slope	acceleration
	area	distance

3. First divide the area below the graph into a triangular part (0 s to 3.0×10^{-3} s) and a rectangular part (3.0×10^{-3} s to 6.0×10^{-3} s).

$$\begin{aligned}\text{Impulse} &= \text{Area below line}\\ &= \text{Area of triangle} + \text{Area of rectangle}\\ &= \frac{1}{2}bh + bh\\ &= \frac{1}{2}\left(3.0\times10^{-3}\text{s}\right)\left(4.0\times10^{3}\text{N}\right) + \left(3.0\times10^{-3}\text{s}\right)\left(4.0\times10^{3}\text{N}\right)\\ &= 6.0\ \text{N}\bullet\text{s} + 12\ \text{N}\bullet\text{s}\\ &= 18\ \text{N}\bullet\text{s}\end{aligned}$$

4. Newton's Second Law states that any unopposed force will result in acceleration (a change in velocity) of the object on which the force acts.

5.


$\vec{F} = m\ \vec{a}$
$\vec{a} = \frac{\Delta\ \vec{v}}{\Delta\ t}$
Newton's Second Law (Algebraic Form)
Acceleration (Algebraic Form)
Combine the formulas by substituting for acceleration.
$\vec{F} = m\frac{\Delta\vec{v}}{\Delta t}$
Remember to include vector notation!
Rearrange the expression by cross multiplying the terms.
$\vec{F}\ \Delta t = m\ \Delta\vec{v}$

6. The left side of the final equation represents the impulse. In question 3 you were finding impulse through force $(\vec{F})$ times change in time (Δt) when you were finding the area.

7. $\vec{p} = m\vec{v}$

8. Impulse $= \vec{F}\Delta t$ or $\vec{I} = \vec{F}\Delta t$

9. $\vec{p}$ and $\vec{J}$ are used because the letters m and I have already been used in physics to represent other quantities – m = mass, and I = electrical current. Thus, to avoid confusion, other symbols should be used.

10. The approaching ball is taken as positive direction and the direction of the bat at point of contact is taken as negative direction. The direction the ball goes after being hit is also a negative direction.

11. a. $\vec{p} = m\vec{v}$

$= (1000\text{ kg})(30.0\text{ m/s})$

$= +3.00\times10^{4}\text{ kg}\bullet\text{m/s}$

$= 3.00\times10^{4}\text{ kg}\bullet\text{m/s}$, in a positive y-direction (3 significant digits)

b. $\vec{p} = m\vec{v}$

$\vec{v} = \dfrac{\vec{p}}{m}$

$= \dfrac{3.00\times10^{4}\text{ kg}\bullet\text{m/s}}{3000\text{ kg}}$

$= +10.0\text{ m/s}$

$= 10.0\text{ m/s}$, in a positive y-direction (3 significant digits)

12. $\vec{I} = \vec{F}\Delta t$

$\vec{F} = \dfrac{\vec{I}}{\Delta t}$

$= \dfrac{4.76\times10^{-2}\text{ N}\bullet\text{s}}{0.170\text{ s}}$

$= +0.280\text{ N}$

$= 0.280\text{ N}$, in a positive x-direction (3 significant digits)

13. $56.7\text{ g} = 5.67\times10^{-2}\text{ kg}$

$\vec{F}\Delta t = m\Delta\vec{v}$

$\vec{F} = \dfrac{m\Delta\vec{v}}{\Delta t}$

$= \dfrac{m(\vec{v}_f - \vec{v}_i)}{\Delta t}$

$= \dfrac{(5.67\times10^{-2}\text{ kg})[+24.0\text{ m/s} - (-25.0\text{ m/s})]}{2.50\times10^{-3}\text{ s}}$ (The negative sign indicates motion is in negative x-direction.)

$= \dfrac{(5.67\times10^{-2}\text{ kg})(49.0\text{ m/s})}{2.50\times10^{-3}\text{ s}}$

$= +1.11\times10^{3}\text{ N}$ (3 significant digits)

Thus, the force must be approximately $1.11\times10^{3}\text{ N}$ in a positive x-direction.

Section 1: Activity 2

1. Both objects show a deformation from their original shape; thus, there must be a force acting on each of the masses.

2. For every force applied there will be an equal but opposite force which results.

3. If no external force acts on an object or system of objects, then the total momentum before a collision is the same as the total momentum after a collision.

4. The assumption is that the only force acting on ball B is that of ball A, and the only force acting on ball A is that of ball B. This assumption is restating the part that states no external force is acting on the object or system of objects.

5. The equation $\Delta\vec{p}_A = -\Delta\vec{p}_B$ tells you that the momentum is transferred completely during the collision.

6. The original momentum of the system is zero. Since momentum is conserved and the rocket exhaust gains momentum, the rocket must move in the opposite direction with equal momentum to counteract the exhaust gas's momentum.

7. The following are completed data charts based on sample data obtained by an Alberta student.

CART A			
Trial Run	Mass of Cart A m_A (g)	Displacement of Cart A $\Delta\vec{d}_A$ (cm)	Product of Mass and Displacement for Cart A $m_A\Delta\vec{d}_A$ (g•cm)
1	368.9	+54.9	$+2.03\times10^4$
2	568.9	+41.5	$+2.36\times10^4$
3	868.9	+36.9	$+3.21\times10^4$

. average of $m_A\Delta\vec{d}_A = \dfrac{7.5924\times10^4 \text{ g}\bullet\text{cm}}{3}$

$= 2.5308\times10^4 \text{ g}\bullet\text{cm}$

$= 2.53\times10^4 \text{ g}\bullet\text{cm}$ (3 significant digits)

CART B			
Trial Run	Mass of Cart B m_A (g)	Displacement of Cart B $\Delta\vec{d}_A$ (cm)	Product of Mass and Displacement for Cart B $m_A\Delta\vec{d}_A$ (g•cm)
1	430.9	−47.3	-2.04×10^4
2	530.9	−48.8	-2.59×10^4
3	930.9	−33.3	-3.10×10^4

average of $m_B\Delta\vec{d}_B = \dfrac{-7.7288\times10^4 \text{ g}\bullet\text{cm}}{3}$

$= -2.5763\times10^4 \text{ g}\bullet\text{cm}$

$= -2.58\times10^4 \text{ g}\bullet\text{cm}$ (3 significant digits)

9. Your completed chart should be similar to the one in the answer to question 7.

10. The product of mass and displacement is close to the same value for Cart A and Cart B.

11. Since the momentum $(\vec{p})$ is proportional to the mass times displacement for Cart A and Cart B, you can say that the momentum for Cart A is close to the same value as the momentum for Cart B; therefore, momentum is conserved in this investigation.

12. They are listed as negative because Cart A and Cart B travelled in opposite directions.

13. You could run the experiment once with three trials, then reverse the position of the carts and repeat the experiment for another three trials. Averaging the results will allow for the acceleration to cancel from your results.

Section 1: Activity 3

1. Total momentum before the collision equals total momentum after the collision. Since the freight car is stationary, its momentum, $\vec{P}_B$, before the collision is zero.

$$\vec{p}_A + \vec{p}_B = \vec{p}_{AB}'$$
$$m_A\vec{v}_A = (m_A + m_B)\vec{v}_{AB}'$$
$$(3.00\times10^4\ \text{kg})(4.00\ \text{m/s}) = (3.00\times10^4\ \text{kg} + 5.00\times10^4\ \text{kg})(\vec{v}_{AB}')$$
$$1.20\times10^5\ \text{kg}\bullet\text{m/s} = (8.00\times10^4\ \text{kg})(\vec{v}_{AB}')$$
$$\vec{v}_{AB}' = \frac{1.20\times10^5\ \text{kg}\bullet\text{m/s}}{8.00\times10^4\ \text{kg}}$$
$$= 1.50\ \text{m/s}$$

The final velocity of the cars is 1.50 m/s in a positive x-direction.

2. Total momentum before the collision equals total momentum after the collision.

$$\vec{p}_A + \vec{p}_B = \vec{p}_{AB}'$$
$$m_A\vec{v}_A + m_B\vec{v}_B = (m_A + m_B)\vec{v}_{AB}'$$
$$(15.0\ \text{kg})(5.50\ \text{m/s}) + (6.00\ \text{kg})(-8.00\ \text{m/s}) = (15.0\ \text{kg} + 6.00\ \text{kg})(\vec{v}_{AB}')$$
$$82.5\ \text{kg}\bullet\text{m/s} + (-48.0\ \text{kg}\bullet\text{m/s}) = (21.0\ \text{kg})(\vec{v}_{AB}')$$
$$34.5\ \text{kg}\bullet\text{m/s} = (21.0\ \text{kg})(\vec{v}_{AB}')$$
$$\vec{v}_{AB}' = \frac{34.5\ \text{kg}\bullet\text{m/s}}{21.0\ \text{kg}}$$
$$= +1.64\ \text{m/s}\ \ (3\ \text{significant digits})$$

The velocity of the combined mass after the collision is approximately 1.64 m/s in a positive x-direction.

Total momentum before the collision equals total momentum after the collision.

$$\vec{p}_A + \vec{p}_B = \vec{p}_A{}' + \vec{p}_B{}'$$

$$m_A\vec{v}_A = m_A\vec{v}_A{}' + m_B\vec{v}_B{}' \quad (\text{Note: } \vec{p}_B = 0)$$

$$(150\text{ g})(300\text{ cm/s}) = (150\text{ g})\left(\vec{v}_A{}'\right) + (400\text{ g})(85.0\text{ cm/s})$$

$$4.50\times10^4\text{ g}\bullet\text{cm/s} = (150\text{ g})\left(\vec{v}_A{}'\right) + 3.40\times10^4\text{ g}\bullet\text{cm/s}$$

$$4.50\times10^4\text{ g}\bullet\text{cm/s} - 3.40\times10^4\text{ g}\bullet\text{cm/s} = (150\text{ g})\left(\vec{v}_A{}'\right)$$

$$1.10\times10^4\text{ g}\bullet\text{cm/s} = (150\text{ g})\left(\vec{v}_A{}'\right)$$

$$\vec{v}_A{}' = \frac{1.10\times10^4\text{ g}\bullet\text{cm/s}}{150\text{ g}}$$

$$= +73.3\text{ cm/s}$$

$$= 73.3\text{ cm/s, in a positive } y\text{-direction (3 significant digits)}$$

The velocity of the 150 g mass will be approximately 73.3 cm/s in a positive y-direction.

Total momentum before the collision equals total momentum after the collision.

$$\vec{p}_A + \vec{p}_B = \vec{p}_{AB}{}'$$

$$m_A\vec{v}_A = (m_A + m_B)\left(\vec{v}_{AB}{}'\right) \quad (\text{Note: } \vec{p}_B = 0)$$

$$(20.0\text{ g})(600\text{ m/s}) = (20.0\text{ g} + m_B)(35.0\text{ m/s})$$

$$1.20\times10^4\text{ g}\bullet\text{m/s} = (20.0\text{ g} + m_B)(35.0\text{ m/s})$$

$$\frac{1.20\times10^4\text{ g}\bullet\text{m/s}}{35.0\text{ m/s}} = (20.0\text{ g} + m_B)$$

$$3.4286\times10^2\text{ g} = 20.0\text{ g} + m_B$$

$$m_B = 342.86\text{ g} - 20.0\text{ g}$$

$$= 322.86\text{ g}$$

$$= 323\text{ g (3 significant digits)}$$

The mass of the block is approximately 323 g.

5. Total momentum before the collision equals total momentum after the collision.

$$\vec{p}_A + \vec{p}_B = \vec{p}_A{}' + \vec{p}_B{}'$$
$$m_A\vec{v}_A + m_B\vec{v}_B = m_A\vec{v}_A{}' + m_B\vec{v}_B{}'$$
$$(200\text{ g})(-100\text{ cm/s}) + (500\text{ g})(-60.0\text{ cm/s}) = (200\text{ g})\left(v_A{}'\right) + (500\text{ g})(-75.0\text{ cm/s})$$
$$-2.00\times10^4\text{ g cm/s} - 3.00\times10^4\text{ g cm/s} = (200\text{ g})\left(v_A{}'\right) - 3.75\times10^4\text{ g cm/s}$$
$$-5.00\times10^4\text{ g cm/s} = (200\text{ g})\left(v_A{}'\right) - 3.75\times10^4\text{ g cm/s}$$
$$-5.00\times10^4\text{ g cm/s} + 3.75\times10^4\text{ g cm/s} = (200\text{ g})\left(v_A{}'\right)$$
$$-1.25\times10^4\text{ g cm/s} = (200\text{ g})\left(v_A{}'\right)$$
$$v_A{}' = \frac{-1.25\times10^4\text{ g cm/s}}{200\text{ g}}$$
$$= -62.5\text{ cm/s}$$
$$= 62.5\text{ cm/s, in a negative } x\text{-direction}$$

The final velocity of the 200 g mass is 62.5 cm/s in a negative x-direction.

6. Total momentum before the skateboarder jumps equals total momentum after the skateboarder jumps.

$$\vec{p}_{AB} = \vec{p}_A{}' + \vec{p}_B{}'$$
$$(m_A + m_B)\vec{v}_{AB} = m_A\vec{v}_A{}' + m_B\vec{v}_B{}'$$
$$(60.0\text{ kg} + 3.00\text{ kg})(2.00\text{ m/s}) = (60.0\text{ kg})(-0.100\text{ m/s}) + (3.00\text{ kg})\left(\vec{v}_B{}'\right)$$
$$(63.0\text{ kg})(2.00\text{ m/s}) = (60.0\text{ kg})(-0.100\text{ m/s}) + (3.00\text{ kg})\left(\vec{v}_B{}'\right)$$
$$126\text{ kg}\bullet\text{m/s} = -6.00\text{ kg}\bullet\text{m/s} + (3.00\text{ kg})\left(\vec{v}_B{}'\right)$$
$$126\text{ kg}\bullet\text{m/s} + 6.00\text{ kg}\bullet\text{m/s} = (3.00\text{ kg})\left(\vec{v}_B{}'\right)$$
$$132\text{ kg}\bullet\text{m/s} = (3.00\text{ kg})\left(\vec{v}_B{}'\right)$$
$$\vec{v}_B{}' = \frac{132\text{ kg}\bullet\text{m/s}}{3.00\text{ kg}}$$
$$= +44.0\text{ m/s}$$
$$= 44.0\text{ m/s, in a positive } x\text{-direction}$$

The final velocity of the skateboard is 44.0 m/s in a positive x-direction.

7. a. According to Newton's Third Law or the Law of Conservation of Momentum, the spacecraft will move in the opposite direction.

b. The momentum before the jump is equal to the sum of the momentum of the spacecraft and the astronaut after the jump.

$$\begin{aligned}
0 &= \vec{p}_A{}' + \vec{p}_B{}' \\
\vec{p}_A{}' &= -\vec{p}_B{}' \\
m_A\vec{v}_A{}' &= -m_B\vec{v}_B{}' \\
(4.50\times10^4\ \text{kg})(\vec{v}_A{}') &= -(100\ \text{kg})(8.00\ \text{m/s}) \\
(4.50\times10^4\ \text{kg})(\vec{v}_A{}') &= -800\ \text{kg}\bullet\text{m/s} \\
\vec{v}_A{}' &= \frac{-800\ \text{kg}\bullet\text{m/s}}{4.50\times10^4\ \text{kg}} \\
&= -1.78\times10^{-2}\ \text{m/s}\ \ (3\ \text{significant digits})
\end{aligned}$$

The velocity of the spacecraft relative to the astronaut is approximately 1.78×10^{-3} m/s in the opposite direction to the direction the astronaut jumped.

8. a. The purpose was to provide a source by which an explosion and consequently a recoil could occur. If an astronaut were to become separated from the spacecraft, a bullet could be fired in the opposite direction of the spacecraft in order to gain momentum toward the spacecraft.

b. The momentum before the pistol is fired is equal to the sum of the momentum of the bullet and astronaut after the pistol is fired. To find how long it will take the astronaut to get to the spacecraft, solve for Δt in the following formula.

$$\begin{aligned}
0 &= \vec{p}_A + \vec{p}_B \\
\vec{p}_A{}' &= -\vec{p}_B{}' \\
(100\ \text{kg})(\vec{v}_A{}') &= -(0.0500\ \text{kg})(300\ \text{m/s}) \\
\vec{v}_A{}' &= \frac{-15.0\ \text{kg m/s}}{100\ \text{kg}} \\
&= -0.150\ \text{m/s} \\
&= 0.150\ \text{m/s, in the opposite direction of the bullet}
\end{aligned}$$

$$\begin{aligned}
\vec{v} &= \frac{\Delta\vec{d}}{\Delta t} \\
\Delta t &= \frac{\Delta\vec{d}}{\vec{v}} \\
t &= \frac{2.00\times10^3\ \text{m}}{0.150\ \text{m/s}} \\
&= 1.33\times10^4\ \text{s} \\
&= 3.70\ \text{h}\ \ (3\ \text{significant digits})
\end{aligned}$$

The astronaut would make it back to the ship before the oxygen runs out.

Section 1: Extra Help

1. Force can change the speed of an object as well as the direction of motion.

2. The motion of an object will only change when a force is applied.

3. The motion of a small mass is easier to change. $F = ma$; thus if m is smaller , then F is smaller.

4. Since $a = \frac{\Delta v}{\Delta t}$ and $F = ma$, then $F = \frac{m\Delta v}{\Delta t}$.

5.

Quantity	Definition	Formula
Force	an action that changes a body's velocity or direction	$\vec{F} = m\vec{a}$
Velocity	distance divided by the time to cover that distance	$\vec{v} = \frac{\Delta \vec{d}}{\Delta t}$
Impulse	the product of the force and the time over which the force acts	$\vec{I} = \vec{F}\Delta t$
Momentum	the product of the mass and velocity for a moving object	$\vec{p} = m\vec{v}$

6. a. $\vec{p} = m\vec{v}$

$= 2000\ \text{kg}(+27.8\ \text{m/s})$

$= +5.56 \times 10^4\ \text{kg} \bullet \text{m/s}$

$= 5.56 \times 10^4\ \text{kg} \bullet \text{m/s}$, in a positive x-direction

The initial momentum of the car was $5.56 \times 10^4\ \text{kg} \bullet \text{m/s}$ in a positive x-direction.

b. Since the final momentum of the car was zero, then the change in momentum is $-5.56 \times 10^4\ \text{kg} \bullet \text{m/s}$ or $5.56 \times 10^4\ \text{kg} \bullet \text{m/s}$, in a negative x-direction.

c. $\vec{F}\Delta t = m\Delta\vec{v}$

$\vec{F}(6.00 \times 10^{-2}\ \text{s}) = (2000\ \text{kg})(-27.8\ \text{m/s})$

$$\vec{F} = \frac{-5.56 \times 10^4\ \text{kg} \bullet \text{m/s}}{6.00 \times 10^{-2}\ \text{s}}$$

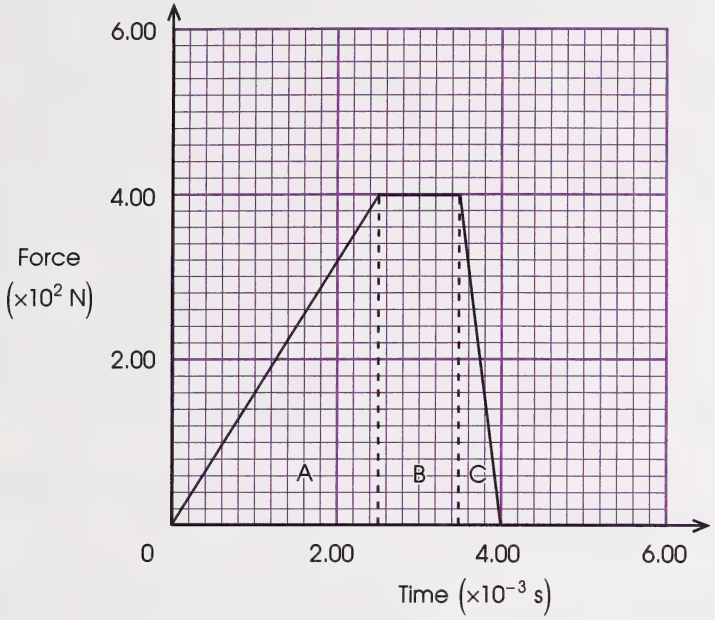
$= -9.27 \times 10^5\ \text{kg} \bullet \text{m/s}^2$

$= 9.27 \times 10^5\ \text{kg} \bullet \text{m/s}^2$, in a negative x-direction (3 significant digits)

The force which acted on the car was approximately $9.27 \times 10^5\ \text{kg} \bullet \text{m/s}^2$ in a negative x-direction.

7. a.

Simplified Graph of a Force Acting on a Ball During Collision



Impulse is the area below the graph.

$$\begin{aligned}\vec{I} &= \text{Area A} + \text{Area B} + \text{Area C} \\ &= \frac{1}{2}(400\text{ N})(2.50\times10^{-3}\text{ s}) + (400\text{ N})(1.00\times10^{-3}\text{ s}) + \frac{1}{2}(400\text{ N})(0.50\times10^{-3}\text{ s}) \\ &= 0.500\text{ N}\bullet\text{s} + 0.400\text{ N}\bullet\text{s} + 0.100\text{ N}\bullet\text{s} \\ &= +1.00\text{ N}\bullet\text{s} \\ &= 1.00\text{ N}\bullet\text{s, in a positive } x\text{-direction}\end{aligned}$$

b. $\vec{F}\Delta t = m\Delta\vec{v}$ and $\vec{I} = \vec{F}\Delta t$

$$\therefore \vec{I} = m\Delta\vec{v}$$

$$1.00\text{ N}\bullet\text{s} = (0.0500\text{ kg})\Delta\vec{v}$$

$$\begin{aligned}\Delta\vec{v} &= \frac{1.00\text{ N}\bullet\text{s}}{0.0500\text{ kg}} \\ &= +20.0\text{ m/s} \\ &= 20.0\text{ m/s, in the positive } x\text{-direction}\end{aligned}$$

8. $$m_1\vec{v}_1 + m_2\vec{v}_2 = m_1\vec{v}_1{}' + m_2\vec{v}_2{}'$$

$$(6.00\text{ kg})(+3.00\text{ m/s}) + (10.0\text{ kg})(+2.00\text{ m/s}) = (6.00\text{ kg})\left(\vec{v}_1{}'\right) + (10.0\text{ kg})(+2.50\text{ m/s})$$

$$18.0\text{ kg}\bullet\text{m/s} + 20.0\text{ kg}\bullet\text{m/s} = (6.00\text{ kg})\left(\vec{v}_1{}'\right) + 25.0\text{ kg}\bullet\text{m/s}$$

$$38.0\text{ kg}\bullet\text{m/s} - 25.0\text{ kg}\bullet\text{m/s} = 6.00\text{ kg}\left(\vec{v}_1{}'\right)$$

$$\left(\vec{v}_1{}'\right) = \frac{13.00\text{ kg}\bullet\text{m/s}}{6.00\text{ kg}}$$

$$= +2.17\text{ m/s}$$

$$= 2.17\text{ m/s, in a positive } x\text{-direction (3 significant digits)}$$

The velocity of the 6.00 kg object after the collision is about 2.17 m/s in a positive x-direction.

9. Total momentum before the push was zero. Sum of the momentum after the push is also zero.

$$0 = m_1\vec{v}_1{}' + m_2\vec{v}_2{}'$$

$$0 = (60.0\text{ kg})(+3.00\text{ m/s}) + m_2(-4.00\text{ m/s})$$

$$-(m_2)(-4.00\text{ m/s}) = 180\text{ kg}\bullet\text{m/s}$$

$$m_2 = \frac{180\text{ kg}\bullet\text{m/s}}{4.00\text{ m/s}}$$

$$= 45.0\text{ kg}$$

The mass of the second skater is 45.0 kg.

10. The collapsible bumpers allow the same force to act over a longer time period; therefore, the impact on the passengers is lessened. You know that impulse is force times change in time. If impulse is the same for both cars and change in time is greater for the car with the collapsible bumper, then the force must be smaller for the car with the collapsible bumper.

Section 1: Enrichment

1. The traffic investigator measures the displacements of the cars from the site of the collision.

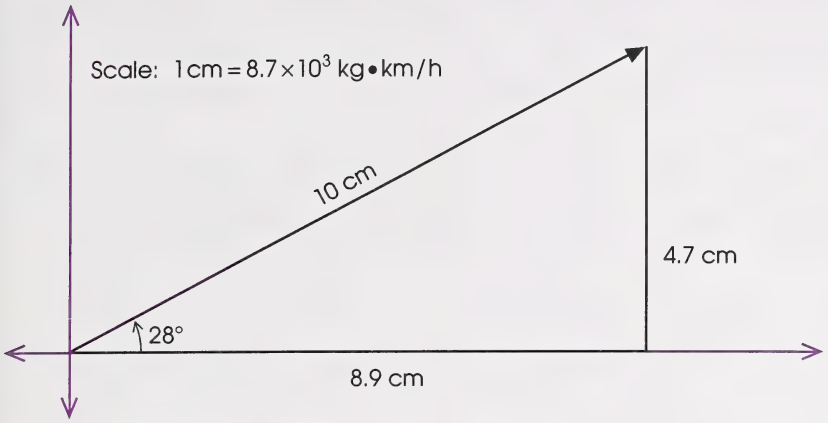
2. The mass of the car and the velocities are estimated. The mass of the car is estimated by adding the mass of the contents, including passengers, to the mass of the car. The velocities are estimated from skid marks and the displacement of the cars from the collision site.

3. $\vec{p} = m\vec{v}$

$\vec{p} = (1100\text{ kg})(71\text{ km/h})$

$= 7.8\times10^4\text{ kg}\bullet\text{km/h}$ (2 significant digits)

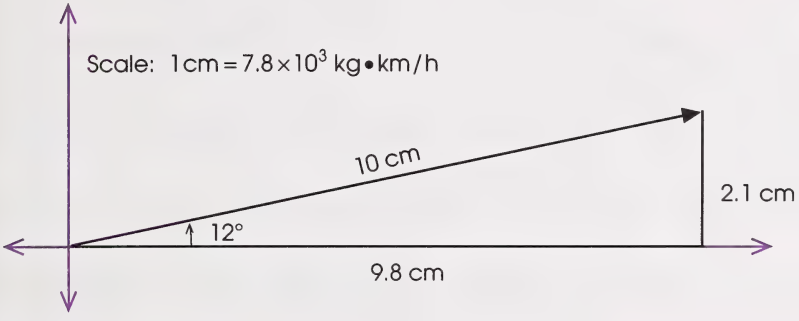
4. The following are horizontal and vertical components for Car 1.



Horizontal Component $= 8.9\text{ cm} \times 8.7 \times 10^3\text{ kg} \bullet \text{km/h/cm}$
$= 7.7 \times 10^4\text{ kg} \bullet \text{km/h}$ (2 significant digits)

Vertical Component $= 4.7\text{ cm} \times 8.7 \times 10^3\text{ kg} \bullet \text{km/h/cm}$
$= 4.1 \times 10^4\text{ kg} \bullet \text{km/h}$ (2 significant digits)

The following are horizontal and vertical components for Car 2.



Horizontal Component $= 9.8\text{ cm} \times 7.8 \times 10^3\text{ kg} \bullet \text{km/h/cm}$
$= 7.6 \times 10^4\text{ kg} \bullet \text{km/h}$ (2 significant digits)

Vertical Component $= 2.1\text{ cm} \times 7.8 \times 10^3\text{ kg} \bullet \text{km/h/cm}$
$= 1.6 \times 10^4\text{ kg} \bullet \text{km/h}$ (2 significant digits)

5.

Horizontal	Vertical
Total momentum before the collision is equal to total momentum after the collision.	Total momentum is equal to the total momentum after the collision.
$\vec{p}_1 + \vec{p}_2 = \vec{p}_{1hor}{}' + \vec{p}_{2hor}{}'$ $\vec{p}_1 + 0 = \left(7.7\times10^4 + 7.6\times10^4\right)\text{kg}\bullet\text{km/h}$ $= 1.5\times10^5\ \text{kg}\bullet\text{km/h}$ (2 significant digits)	$\vec{p}_1 + \vec{p}_2 = \vec{p}_{1ver}{}' + \vec{p}_{2ver}{}'$ $0 + \vec{p}_2 = \left(4.1\times10^4 + 1.6\times10^4\right)\text{kg}\bullet\text{km/h}$ $\vec{p}_2 = 5.7\times10^4\ \text{kg}\bullet\text{km/h}$

6. The horizontal momentum is approximately $1.5\times10^5\ \text{kg}\bullet\text{km/h}$.

Car 1 had approximately $1.5\times10^5\ \text{kg}\bullet\text{km/h}$.

$$\vec{p} = m\vec{v}$$
$$1.5\times10^5\ \text{kg}\bullet\text{km/h} = (1500\ \text{kg})(\vec{v})$$
$$\vec{v} = \frac{1.5\times10^5\ \text{kg}\bullet\text{km/h}}{1500\ \text{kg}}$$
$$= 1.0\times10^2\ \text{km/h}\ \text{(2 significant digits)}$$

Car 2 had approximately $5.7\times10^4\ \text{kg}\bullet\text{km/h}$.

$$\vec{p} = m\vec{v}$$
$$5.7\times10^4\ \text{kg}\bullet\text{km/h} = (1100\ \text{kg})(\vec{v})$$
$$\vec{v} = \frac{5.7\times10^4\ \text{kg}\bullet\text{km/h}}{1100\ \text{kg}}$$
$$= 52\ \text{km/h}\ \text{(2 significant digits)}$$

7. Car 1 was speeding. This agrees with the conclusions of the investigator.

Section 2: Activity 1

1. All objects remain at rest or in a straight line at a constant speed unless acted upon by an unbalanced force.

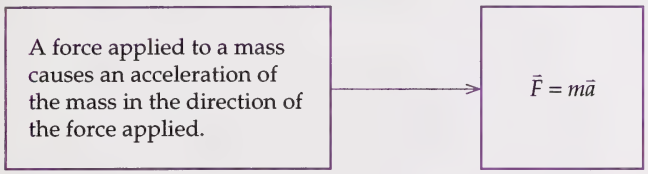
2.

Mass of Container	Speed of Container	Radius of Circle	Force to Keep Container in Circle
small	constant	constant	small
large	constant	constant	large
constant	slow	constant	small
constant	fast	constant	large
constant	constant	small	large
constant	constant	large	small

3. The partially full container required the most force. Since it was more massive, it would have more inertia, and thus more of a tendency to move in a straight line – requiring more force to move into a curve.

4. The faster spin was harder to hold in a circular path.

5.



Newton's Second Law (Qualitative) Newton's Second Law (Algebraic)

6. The force was acting toward your hand since it was keeping the plastic container from flying away from your hand.

7. The plastic container would fly in a perpendicular direction to the cord or to the direction of the force.

8. $F_c = \dfrac{(m)(v)^2}{(r)}$

Section 2: Activity 2

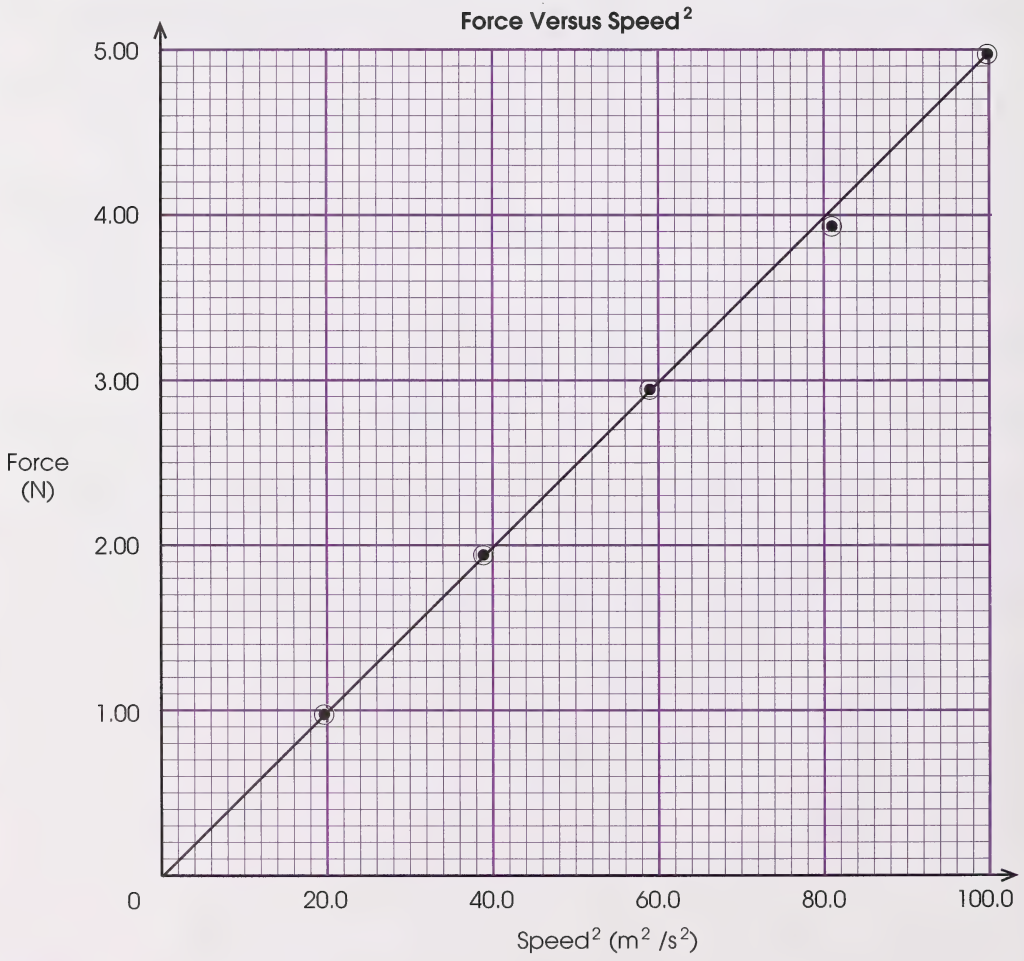
1. Answers will vary. The following are the values from Part B.

radius of circle = **0.800** m
mass of stopper = **0.0393** kg

2. Answers will vary. The following chart is based on the data from Part B.

Hanging Mass (kg)	Centripetal Force (N)	Time for 25 Revolutions (s)	Time for 1 Revolution (s)	Speed of Mass (m/s)	Speed^2 (m^2/s^2)
0.100	0.981	28.3	1.13	4.44	19.7
0.200	1.96	20.0	0.800	6.28	39.5
0.300	2.94	16.4	0.656	7.66	58.7
0.400	3.92	14.0	0.560	8.98	80.6
0.500	4.91	12.6	0.504	9.97	99.5

3.



4. Yes, a direct variation such as $F_c \propto v^2$ should give a straight line graph.

5. Since the time is greatly influenced by human reaction time, measuring the time for one revolution is difficult to do precisely. This problem becomes negligible when twenty-five revolutions are measured.

6. The stopper was spun in a horizontal circle because in a vertical circle gravity would cause the stopper to accelerate and decelerate in its path.

7.

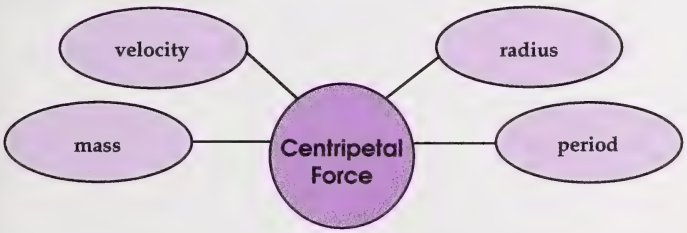
Centripetal Force (N)	Experimental Orbital Period (time for one revolution) (s)	Theoretical Orbital Period (s)	% error
0.981	1.13	1.12	0.893
1.96	0.800	0.796	0.503
2.94	0.656	0.650	0.923
3.92	0.560	0.563	0.533
4.91	0.504	0.503	0.199

$\%\ \text{error}_{(\text{ave})} = \mathbf{0.610}$

8. The formula $F_c = \dfrac{4\pi^2 mr}{T^2}$ is a suitable expression for centripetal force since it produces values very close to measured values.

Section 2: Activity 3

1.



2. The data is as follows:

$m = 1300\ \text{kg}$
$r = 8.00\ \text{m}$
$v = 5.00\ \text{m/s}$

The solution is as follows:

$$F_c = \frac{mv^2}{r}$$
$$= \frac{(1300\ \text{kg})(5.00\ \text{m/s})^2}{8.00\ \text{m}}$$
$$= 4.06 \times 10^3\ \text{N} \quad \text{(3 significant digits)}$$

The minimum force required to maintain the car in the circular path is approximately 4.06×10^3 N.

3. The data is as follows:

$m = 40.0 \text{ kg}$
$r = 1.50 \text{ m}$
$T = 2.00 \text{ s}$

The solution is as follows:

$$F_c = \frac{4\pi^2 mr}{T^2}$$
$$= \frac{4\pi^2 (40.0 \text{ kg})(1.50 \text{ m})}{(2.00 \text{ s})^2}$$
$$= 592 \text{ N} \quad (3 \text{ significant digits})$$

The minimum force required by the child is approximately 592 N.

4. **Textbook question 1:**

The data is as follows:

$m = 4.0 \text{ kg}$
$v = 2.0 \text{ m/s}$
$F_c = 6.4 \text{ N}$

The solution is as follows:

$$F_c = \frac{mv^2}{r}$$
$$F_c r = mv^2$$
$$r = \frac{mv^2}{F_c}$$
$$= \frac{(4.0 \text{ kg})(2.0 \text{ m/s})^2}{6.4 \text{ N}}$$
$$= 2.5 \text{ m}$$

The radius of the ball's path is 2.5 m.

Textbook question 2:

The data is as follows:

$m = 9.11 \times 10^{-31} \text{ kg}$
$r = 5.29 \times 10^{-11} \text{ kg}$
$F_c = 8.22 \times 10^{-8} \text{ N}$
$d = 6182 \text{ km}$

Change 6182 km to m.

$$d = 6182 \cancel{\text{km}} \times \frac{1000 \text{ m}}{1 \cancel{\text{km}}}$$
$$= 6\,182\,000 \text{ m}$$
$$= 6.182 \times 10^6 \text{ m}$$

The solution is as follows:

$$F_c = \frac{mv^2}{r}$$
$$F_c r = mv^2$$
$$v^2 = \frac{F_c r}{m}$$
$$v = \sqrt{\frac{F_c r}{m}}$$
$$= \sqrt{\frac{(8.22\times10^{-8}\ \text{N})(5.29\times10^{-11}\ \text{m})}{9.11\times10^{-31}\ \text{kg}}}$$
$$= 2.1848\times10^{6}$$
$$= 2.18\times10^{6}\ \text{m/s}\ \text{(3 significant digits)}$$

$$v = \frac{d}{t}$$
$$t = \frac{d}{v}$$
$$= \frac{6.182\times10^{6}\ \text{m}}{2.1848\times10^{6}\ \text{m/s}}$$
$$= 2.83\ \text{s}\ \text{(3 significant digits)}$$

The speed of the electron is approximately 2.18×10^{6} m/s. It would take about 2.83 s to get from Halifax to Vancouver.

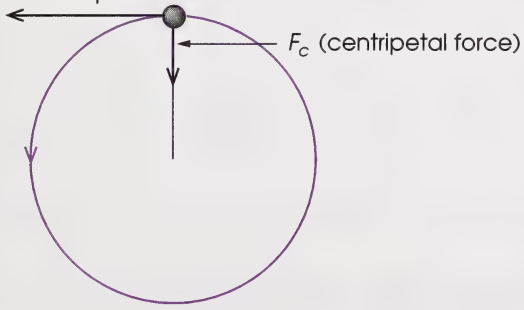
5. A centrifuge works by spinning a container of whatever solution you want to separate in a circle. As the material is spun, the heavier particles go to the outside forming layers of different density of substances.

6. An analytical ultracentrifuge is an extremely precise centrifuge which can measure the rate at which molecules as small as proteins move through a solution due to the centrifugal effect. It is used to separate strands of DNA that have different densities.

7. **Textbook question 1:** He did not experience an outward push. He merely had a tendency to go in a straight line. However, the tracks kept him in the circle which he interpreted as an inward push of the tracks on him. The tracks seemed to push him inward while he seemed to push outward.

Section 2: Extra Help

1. instantaneous speed



2. a. An increase in the mass of an object requires an **increase** in the amount of force applied to keep the mass moving in a circle.

   b. As the radius of an object's circular path increases, the amount of force needed to hold the object in that circle will **decrease**.

c. As the instantaneous speed of the object increases, the centripetal force must **increase** to maintain the same radius.

3. Velocity has both magnitude and direction. Although the magnitude of the velocity does not change, the direction of the velocity is always changing. This change in direction of the velocity is considered as an acceleration perpendicular to the direction of the velocity.

4. The data is as follows:

$m = 9.11 \times 10^{-31}\ \text{kg}$
$v = 2.50 \times 10^{4}\ \text{m/s}$
$r = 20.0\ \text{cm}$

The solution is as follows:

$$F = \frac{mv^2}{r}$$
$$= \frac{(9.11 \times 10^{-31}\ \text{kg})(2.50 \times 10^{4}\ \text{m/s})^2}{0.200\ \text{m}}$$
$$= 2.85 \times 10^{-21}\ \text{N} \quad \text{(3 significant digits)}$$

Section 2: Enrichment

1. $F_{net} = F_c + F_g$
$$= \frac{mv^2}{r} + mg$$
$$= \frac{(90.0\ \text{kg})(440\ \text{m/s})^2}{2.00 \times 10^{3}\ \text{m}} + (90.0\ \text{kg})(9.81\ \text{m/s}^2)$$
$$= 8.712 \times 10^{3}\ \text{N} + 882.9\ \text{N}$$
$$= 9.59 \times 10^{3}\ \text{N} \quad \text{(3 significant digits)}$$

The net force acting on the pilot is about $9.59 \times 10^{3}\ \text{N}$.

2. $F_{net} = F_c - F_g$
$0 = F_c - F_g$
$F_c = F_g$

$$\frac{mv^2}{r} = mg$$
$$v^2 = \frac{\cancel{m}gr}{\cancel{m}}$$
$$v = \sqrt{gr}$$
$$= \sqrt{(9.81\ \text{m/s}^2)(10.0\ \text{m})}$$
$$= 9.90\ \text{m/s} \quad \text{(3 significant digits)}$$

The necessary speed is approximately 9.90 m/s.

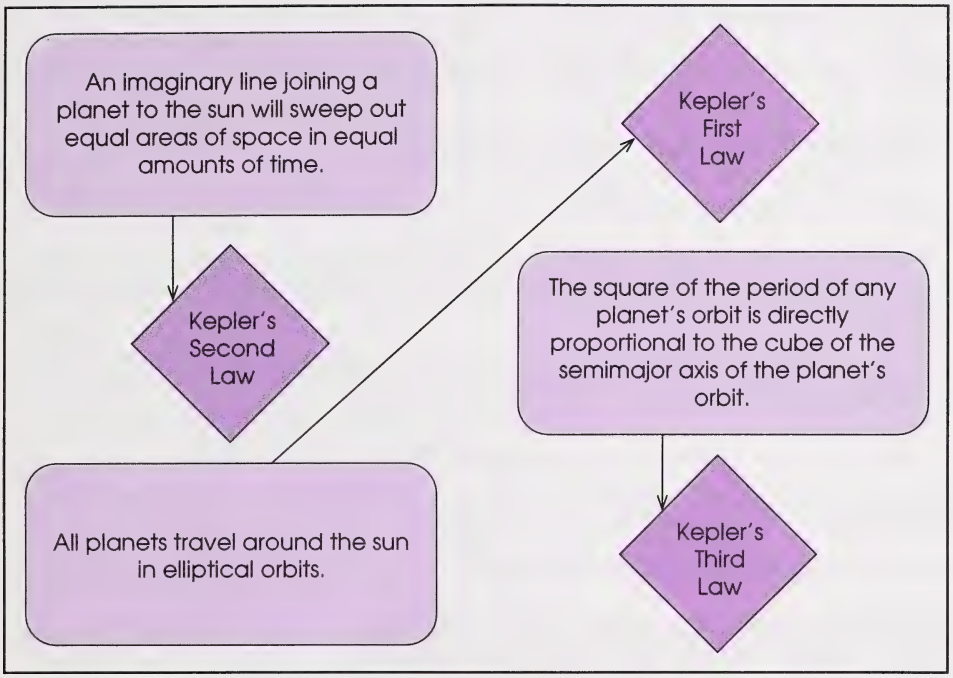
3. $T = \dfrac{1\ \text{revolution}}{1680\ \text{revolutions/s}}$
$= 5.9524 \times 10^{-4}\ \text{s}$

$$F_c = \frac{4\pi^2 mr}{T^2}$$
$$= \frac{4\pi^2 (9.11 \times 10^{-31}\ \text{kg})(0.100\ \text{m})}{(5.9524 \times 10^{-4}\ \text{s})^2}$$
$$= 1.02 \times 10^{-23}\ \text{N} \quad \text{(3 significant digits)}$$

Section 3: Activity 1

1. a. Kepler
   b. Copernicus
   c. Tycho Brahe
   d. Ptolemy
   e. Newton
   f. epicycle

2. His extremely accurate observations were the real value of his work. They were used by Kepler to predict the noncircular paths of the planets.

3. 
An imaginary line joining a planet to the sun will sweep out equal areas of space in equal amounts of time.
Kepler's First Law
Kepler's Second Law
The square of the period of any planet's orbit is directly proportional to the cube of the semimajor axis of the planet's orbit.
All planets travel around the sun in elliptical orbits.
Kepler's Third Law

4. The speed of the planet as it travels from C to D must be greater since the distance from C to D is greater than the distance from A to B, and by Kepler's Second Law the time to travel both distances must be the same.

5. $T^2 \propto a^3$. The period (T) squared varies directly as the cube of one-half of the length of the longer axis. (Note that a is not a radius since this is an ellipse not a circle.)

6. Answers may vary. One method is as follows:

   - According to Newton's Law of Universal Gravitation, $F_g = G\frac{m_1 m_2}{r^2}$. Therefore, $G = \frac{F_g r^2}{m_1 m_2}$.
   - To measure the value of G you must measure the force of gravity that exists between two known masses at a fixed distance. By substituting those measures into the equation, G is found.
   - Historically, a known mass is fixed to a long rod suspended from a fixed point by bringing another known mass close to the first mass the rod is made to rotate under the force of attraction between the masses. By comparing the amount of rotation to a previously determined force-to-rotation angle table, force can be found. The values are then substituted into the formula.

Section 3: Activity 2

1. The factors that determine the circular motion of an object are as follows:

    - the mass undergoing the circular motion
    - the radius of the circular path
    - the centripetal force applied to the mass

2. The string supplied centripetal force.

3. The force of gravity supplies the centripetal force thus causing the moon to move in a circular path about the Earth.

4. The centripetal force and the force of gravity for a satellite are equal.

5. The effect of gravity is from the centre of the Earth.

6. Since the satellite has moved, the tracking computer must compensate for this change in position when sending a signal to the satellite. In addition, the satellite is behind the Earth for about 1 h during each orbit and cannot send or receive any signals.

7. a. It is a good description because its orbital period is equal to the period of the Earth's rotation. The result is that the satellite remains over the same spot on the Earth.

    b. A remote sensing satellite is designed to survey regions of the globe, not just one spot.

Section 3: Activity 3

1. Answers may vary. Some possible answers are as follows:

    - used as a station for construction and launch of exploration craft
    - used as a base for research into low gravity and vacuum conditions
    - used as a base for monitoring Earthside conditions such as weather and land use
    - used as a based for deep space research with telescopes

2. The RADARSAT is used to collect data about forestry conditions; vegetation; agricultural conditions; ground moisture; and surface conditions for fishing, shipping, and oil exploration.

3. It is a remote manipulator system designed to deploy and retrieve materials from the space shuttle's cargo bay. It has also been used to retrieve satellites from space and bring them into the cargo bay for repair.

4. Some of the experiments performed include the following:

    - the study of the ozone layer (Garneau)

    - the effects of weightlessness on the human body, such as nervous reflexes, human metabolism, etc. (Bondar)

    - the experiments on visual targeting systems for the Canadarm, and effects of space on various materials on the exposed surfaces of spacecraft (MacLean)

5. a. The plane flies a "rollercoaster" path. As the plane drops the astronauts inside experience free fall, which is a sensation equivalent to zero gravity.

   b. Humans who train in this airplane experience motion sickness which often results in vomiting.

6. Answers may vary. The following chart lists some advantages and disadvantages which may be included.

Advantages	Disadvantages
• easy to move large masses around • allows for certain technologies and industries to function • makes docking of spacecraft simple	• produces medical problems with onboard residents • many changes to daily living necessary, i.e., eating, sleeping, hygiene

7. The following are possible answers.

   Group two
   - Proposed areas of research and development involve manufacture of crystals used in pharmaceuticals and the computer industry, since such crystal formation is more efficient in the absence of gravity. As well, new materials research could be undertaken.

   Group three
   - The manufacture of complex, precise, inexpensive computer chips could revolutionize Earth-based communications. Purer and newer forms of drugs could help in the treatment of disease.

8. The following are possible answers.

   Ecologist – No way! The construction of all those rockets and parts means increased industry and mining, which increase pollution on Earth. It also means pollution of space.

   Businessperson – What are the costs? My taxes are already too high. Who is going to pay for this?

   Military – Just what we need! Think of the observations that we can make of the Earth from there. What a great surveillance platform!

   Research Scientist – You already know what gravity does! But you can study the effects of a vacuum and deep space.

9. Answers will vary depending on what the student perceives as risks and benefits. However, the student should arrive at some conclusion as to the value of the space program. An example has been provided.

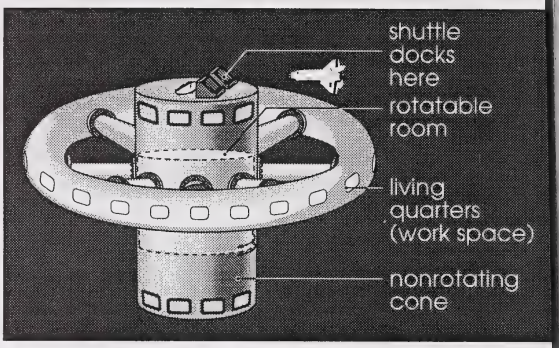
   - Possible benefit areas include medical spinoffs such as monitoring equipment for intensive care, insulating suits and "clean room" technology for contagious disease control, communications technology for navigation and emergency relief.

   - Possible risk areas include damage to ecosystems due to material needs (iron, silicon, etc.) and damage to ozone layer due to rocket exhaust.

10. As you travel in a circle you have a tendency to continue to move in a straight line. The wall of the station presses against you forcing your straight line motion to change direction. That force is interpreted by your brain (and body) as gravity.

11. The following is an example of a possible design.

    - The station could consist of two portions, a nonrotating core and a rotating ring.
    - The shuttle would dock at the end of the nonrotating core.
    - Materials and personnel would enter a rotatable room which would then be spun up to speed with the rotating ring. When speeds match, transfer could occur.



12. The pilot of your shuttle fires the nose thrusters (retro rockets) causing the shuttle to **decelerate**. The change in speed which results causes a **decrease** in the orbital radius of the shuttle. Since the shuttle is in a **lower** orbit, it will have a different orbital period and in effect will be travelling **faster** than the station. The pilot would pull ahead of the station and then fire the tail thrusters to reverse the changes and thus arrive at the station.

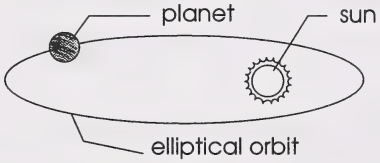
Section 3: Extra Help

1. In the Ptolemaic system, the Earth was at the centre; in the Copernican system, the sun was at the centre. As a result, the Ptolemaic system required a complex system of circles within circles. The Copernican system used one simple circle to attempt to explain the motion of a planet.

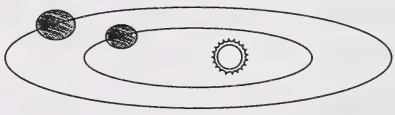
2. The name Tycho Brahe would bring to mind meticulous observational data. As a model, Tycho Brahe saw the Earth at the center of the universe with the sun revolving around the Earth and the planets around the sun.

3. Your sketches should be similar to the following:

Kepler's First Law



Kepler's Third Law



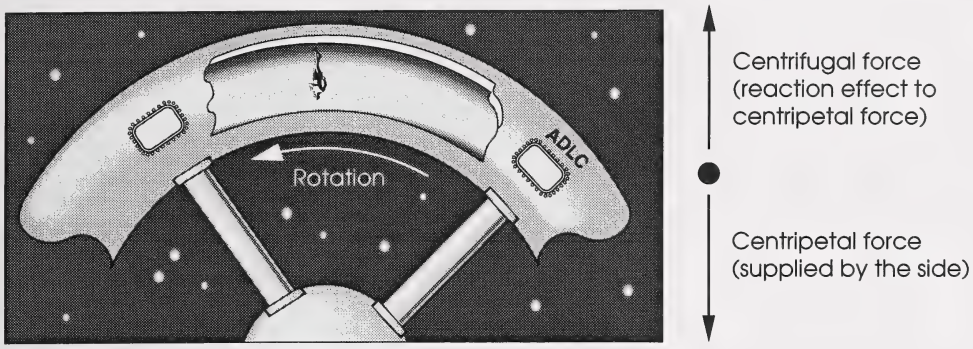
$$\frac{T_1^2}{r_1^3} = \frac{T_2^2}{r_2^3}$$

Kepler's Second Law

Area 1 = Area 2

4. This infers that there is only one possible speed and one altitude for a geostationary satellite orbiting the Earth.

5. a.



b. The centripetal force supplied by the spacecraft wall to produce a change in velocity is interpreted by your brain (and body) as a gravitational force. Notice that the people working would actually have to walk on the "walls."

Section 3: Enrichment

Answers will vary according to your insight. However, areas of change should include the following:

- Respiration
  - Air circulation (O_2 replenishment and CO_2 removal) is decreased (need fans to promote air currents).
- Personal Hygiene
  - Elimination and urination must be accomplished by vacuum (suction).
  - Washing is a problem due to tendency of water to form globules. Showering could be accomplished by forcing the water out under pressure. This in effect would throw the water at you.
- Eating and Drinking
  - Food and drink have a tendency to float away from a person (use sealed containers and drinking tubes).

Centimetre Ruler

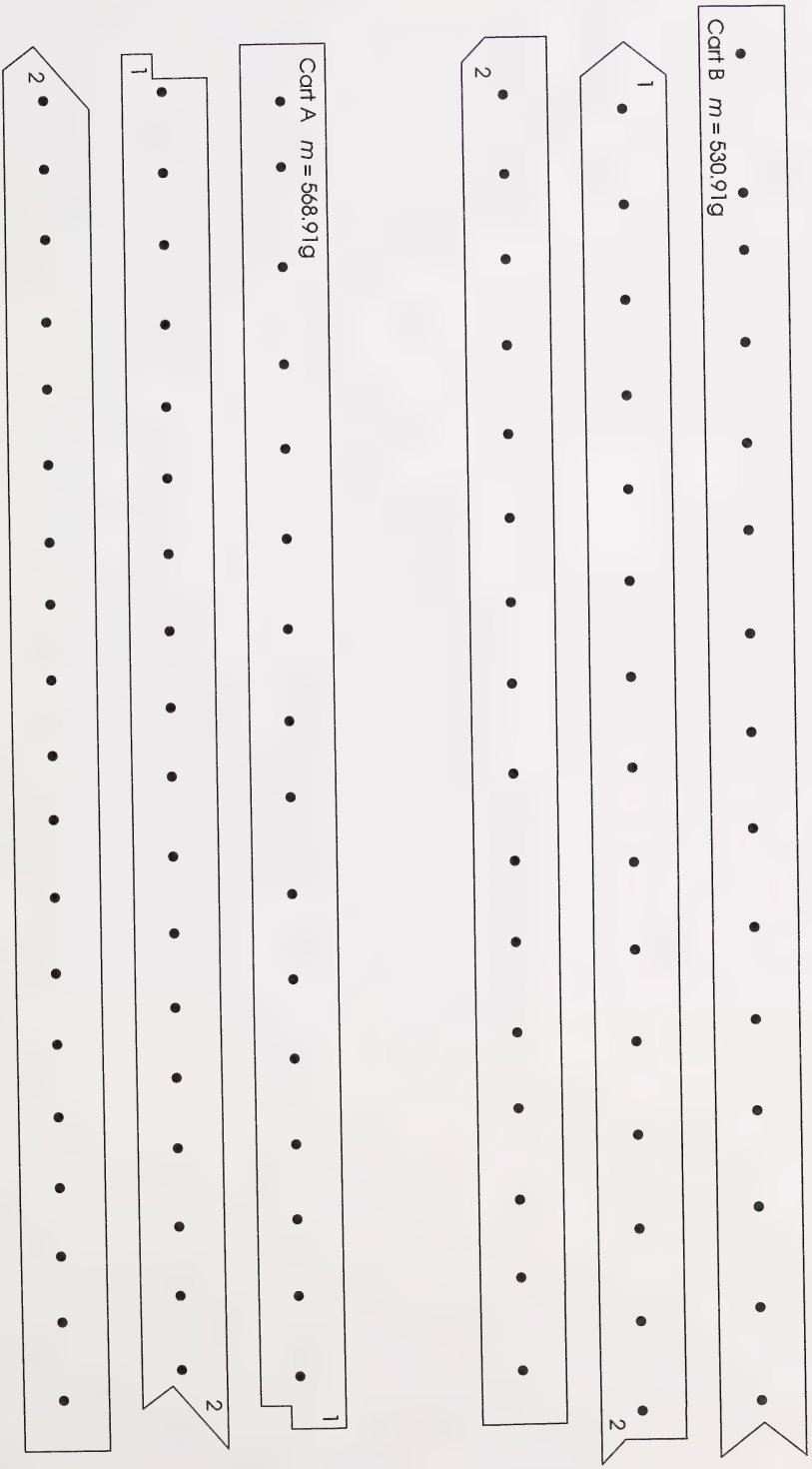
Ticker Tapes Used for Section 1: Activity 2, Investigation: Conservation of Momentum

Part B

Trial 1

Ticker Tapes Used for Section 1: Activity 2, Investigation: Conservation of Momentum

Trial 2



Ticker Tapes Used for Section 1: Activity 2, Investigation: Conservation of Momentum

Trial 3

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Science 20

Student Module Booklet

Module 8

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